FOREWORD

The world is in need of improved technologies using coal, whether they are for advanced cleaner coal power plants or extracting coal in more cost effective, safe and environmentally acceptable ways. Substantial research programmes are underway in a number of countries. The development of cleaner coal technologies in particular, is widely seen as a vital task because of the growing environmental concern about emissions from coal-fired plant.

Although coal is our planet's most abundant form of fossil energy, it could be one of the most environmentally damaging if effective pollution control techniques were not used during its extraction, preparation and combustion. The Environment White Paper, which the Government published in 1990, emphasised the importance of stewardship in looking after our planet for future generations and the Government's leading role in developing sensible and sound policies for the environment. Coal is one of the UK's most important sources of energy, and is likely to remain so in the future. It is therefore essential that the necessary technologies are developed to ensure that coal remains an energy option for the future. Research has a vital part to play in retaining and developing coal as an energy option. One of the main aims of the proposed strategy outlined in this document would be to ensure that the environmental impact of coal winning, preparation and use can meet future environmental constraints, and therefore allow coal to remain an important energy source for future generations.

The Government should recognise its role in providing a framework within which technologies can be developed, and collaboration within industry fostered, to enable coal to continue to play an important role in contributing to future UK energy requirements. This document discusses what further steps are required, and the priorities that should be assigned to them. The various technologies are currently at different stages of development, with some close to the demonstration stage whilst others cannot be expected to achieve commercial status for at least ten years, and possibly longer. The Government cannot make this happen by itself. If these technologies are to achieve commercial status by the beginning of the 21st century, industry will need to become increasingly involved in research, development and demonstration activities to ensure that they are commercialised successfully. To assist this cooperation, the Department of Energy has established a "Coal Task Force", involving representatives of industry and academe, to advise them on the development of a long term strategy. This paper is the result of their work.

SUMMARY

1. Past Department of Energy coal-based research programmes have promoted work which provided technical support for the development of coal policy, where such information would not be available through R&D programmes of the energy industries or from other sources. An important part of these programmes was to promote participation in international collaborative work on coal R&D topics regarded as worthwhile in the national interest. However, with the growing environmental concern with respect to coal as an energy source and the reduction in long term strategic research on coal technology by the energy industries, a major review of the Department's coal-based research programme was timely.

2. This paper therefore sets out a proposed new strategy for the future phases of the Department of Energy's coal technology research, development and demonstration programme following completion of the review. The main priority of the proposed strategy is to ensure that advanced, cleaner technologies are available in the UK by the end of the decade to enable coal to achieve its full economic potential in the energy market. It is expected that at least two thirds of the overall cost of the programme would be spent on cleaner coal technologies, with the remainder on the coal supply technologies. The proposed strategy envisages a collaborative, ten year programme of work, involving Government, manufacturing and the energy supply industries, to achieve the following key aims by the end of the decade:

- **for cleaner coal technologies, the aim is to ensure that there is a firm foundation for the exploitation of cleaner coal technologies in the UK for electricity generation and other industrial uses;**

- **for coal extraction technologies, the aim is to assess the feasibility and potential of novel extraction methods and practices, outside the scope of commercial activities, to enable indigenous coal resources to be exploited safely, economically and in an environmentally acceptable manner;**

- **for coal preparation technologies, the aim is to assess and develop novel techniques, including those capable of handling ultra fine/ultra clean coals, to increase their market acceptability.**

3. In order to achieve the above aims, the programme would support basic science and technology relevant to coal extraction, preparation and utilisation technologies, and the environmental impact of coal.

4. The proposed strategy is intended to provide a framework for maximum industrial participation in the development and implementation of the programme. The programme would also take full advantage of opportunities for international collaboration, particularly with respect to cleaner coal technologies, where they enhance UK activity and enable the aims to be achieved in a more efficient and cost effective manner. Particular emphasis will be given in the proposed strategy to maintaining high standards of

safety and enabling coal to meet the challenge of higher environmental standards being set, more cost effectively.

An outline of the main coal technology sectors, together with the aim, rationale and objectives for research, development and demonstration in each sector, is presented in Appendix 1 to this paper.

Through this proposed strategy, industry would be invited to work in partnership with the Department of Energy to develop the technologies we need to retain coal as an important energy source for the future.

1. INTRODUCTION

1.1. The past twenty years have seen major fluctuations in the price and availability of most energy sources. In the UK we are fortunate to enjoy a considerable range of energy sources, with substantial resources of coal, oil and gas and long experience of nuclear power. Renewable sources of energy are also beginning to make a useful contribution to our energy needs. In an uncertain world, we need to make full use of all available sources of energy to provide diversity of supply. In order to ensure a healthy competitive energy market which is robust to uncertainties in the future (including possible disruptions in the supply from individual sources of energy), a wide range of technology options is needed.

1.2. Coal has met a substantial proportion of the UK's energy requirements for many years, with research playing a vital part in enabling the UK to exploit and utilise its coal resources. However, considerable research effort remains to be undertaken to enable coal to achieve its full economic potential in meeting energy requirements in the UK into the 21st century and beyond.

1.3. Historically, the largest part of public sector coal research and development has been carried out by the British Coal Corporation. Under the 1946 Coal Industry Act, British Coal have a statutory duty to determine whether research into coal related subjects is necessary to secure the future of the industry, and as appropriate, to arrange for it to be undertaken (the Act does not specify any appropriate timescale such research should consider). British Gas and the former Central Electricity Generating Board (CEGB) also supported a wide range of research on coal utilisation and conversion technologies. All these public sector research programmes were reviewed annually by the Advisory Council on Research and Development (ACORD), which advised the Secretary of State on their appropriate size, scope and balance.

1.4. Complementary to the main effort on coal based R&D undertaken by British Coal and the other public sector utilities, the Department of Energy, in support of its general objectives, has funded a modest programme of work for a number of years. The Science and Technology Act of 1965 is the enabling legislation which allows the Department to spend money on Research and Development, however, it places no obligation on the Department to support coal research specifically.

1.5. Within the programme, the Department has generally contributed to projects initiated by other parties eg British Coal, British Gas and the CEGB. Departmental funding has been used as either "seed corn" funding to encourage other parties to contribute, or "top up" funding to cover shortfalls in projects regarded as worthwhile in the national interest. The emphasis was, and still is, on the cleaner use of coal, with projects addressing ways of reducing the environmental impact of energy conversion. The Department's programme promotes work which provides technical support for the development of coal policy, where such information would not be available through the R&D programmes of the energy industries or other sources. An important part of the programme is to promote participation in international collaborative work on coal R&D topics where there are clear advantages to the UK.

Recent changes

1.6. As mentioned in paragraph 1.3, British Coal have provided the bulk of support for coal R&D, although the level of funding has been falling consistently over the past five years. Since 1987, this has been particularly influenced by the objectives set for the Corporation by the Government. These objectives include the requirement that:

"British Coal should aim to maximise its long term profitability by concentrating on those sales which maximise profit on a continuing basis in competition with other fuels. It should plan its marketing, production, capital investment and research and development accordingly."

1.7. These objectives do not remove British Coal's responsibility under the 1946 Act to undertake research aimed at securing future markets, but they do limit severely the extent to which British Coal can fund long term research.

1.8. More recently, the growing competition from imported coal and other fossil fuels has increased the financial pressure on British Coal, and the Corporation has been undergoing a major realignment in order to address these changing circumstances. This has resulted in a concentration of research effort and related activities to addressing short to medium term problems. The size of the programme has also been reduced from £78.9 million in 1981/82 to £28.6 million in 1989/90 (all at 1990/91 prices).

1.9. The privatisation of the electricity supply industry is also having a significant effect on long term research, as the successor companies' research programmes concentrate on short to medium term activities closely linked to commercial considerations.

1.10. All these changes are taking place against a background of increasing restrictions on polluting wastes and emissions which impinge particularly heavily on coal. The changing environmental and economic climate suggests that the future will lie with the development of advanced cleaner coal technologies for new coal-fired plant, rather than the conventional PFC plant used in existing power stations. Particular attention needs to be given to advanced power generation plant, where carbon dioxide (CO_2) emissions are reduced through conversion efficiency improvements and, in addition abatement technologies could be cost effectively added.

The UK coal resource

1.11. Diversity of supply is an important objective for UK energy policy. Indigenous resources are doubly valuable if they can be exploited as economically as similar resources overseas. UK coal resources are substantial, and British Coal's estimate of coal in place in the UK (that is, in seams over 60 cm thick and less than 1,200 metres deep, minus coal which has already been worked) is 190 billion tonnes (British Coal Corporation's 1989/90 Annual Report). The technically recoverable reserves total 45 billion tonnes, with recoverable reserves from existing mines and new mine projects currently assessed at between 3 and 5 billion tonnes. There are also substantial reserves of coal in thick seams between 1200-2000 metres deep, both in mainland UK and under the North Sea. New, as yet undeveloped extraction techniques may allow these substantial resources to be exploited in the future. However, the development of such technologies will require further research, with particular attention paid to health and safety issues. While such R&D will necessarily be directed at providing longer term solutions, it is accepted that shorter term advantage may well also be derived through "spin-off" technologies, particularly in the areas of environmental concern.

1.12. The UK mining industry is a mature industry and now needs to solve problems which younger, overseas industries do not yet have, if UK coals are to continue to play an important role in meeting the nation's energy supply. These problems include mining at depths well in excess of those worked in Australian and US mines, more difficult geological conditions and a high proportion of coals with a sulphur content greater than many world traded coals. The UK mining industry successfully developed longwall mining technology which is now used throughout the world and has maintained an admirable record on health and safety. Mining at greater depths beyond 1200 metres would pose additional environmental problems for the underground workforce, and health and safety issues and reducing geological risk are a priority for research in order to optimise the exploitation of these deep reserves.

The role of Government

1.13. The lack of a market for new coal generating plant in the short term, which would be the main market for coal in the foreseeable future, will limit severely the industrial support for R&D that can be reasonably expected. The Government should accept the need for it to take action to provide a framework to encourage the development and promotion of new cleaner coal technologies, ie technologies which provide methods of preparing, handling, utilising and exploiting coal in the most efficient and environmentally acceptable ways.

1.14. In order to ensure a healthy energy market, a framework is needed in which all economic sources of energy can be produced, supplied and used as efficiently as possible, at the lowest practicable cost, while at the same time meeting acceptable safety and environmental criteria. The strategy proposed in this paper aims to provide such a framework for coal R&D in which industry can play a full role in the development of research plans as well as their implementation.

2. RESEARCH, DEVELOPMENT AND DEMONSTRATION STRATEGY

Research, development and demonstration needs

2.1. In order for coal to continue to play an important role in meeting future energy requirements, the UK will need to have available cleaner coal technology to begin replacing the conventional pulverised fuel power station plant in the early part of the 21st century. The introduction of competition into electricity generation is expected to put pressure on profit margins and the companies are unlikely to be willing to accept significant technical risk in addition to the inevitable commercial risks. The industry therefore need confidence in any new type of plant that may be proposed to replace well tried and tested conventional coal fired plant. An appropriate level of experience and proving of cleaner coal technologies at large size, plus supporting science and technology, will be required before these technologies are accepted by the generating industry and other coal-using industries. Similar requirements exist in coal winning and advanced coal preparation techniques used by the coal extraction and utilisation industries, with the essential caveat that new extraction techniques can be safely employed in an underground environment. More radical extraction techniques may ultimately offer even greater efficiency and environmental gains.

2.2. The development of new, advanced cleaner coal technologies appropriate for the UK, will require a collaborative effort involving the coal mining industry, the utilities and the power plant manufacturing industry. With major changes across much of these sectors either having taken place recently or in prospect, the Government should recognise the need to provide a central focus for the development and promotion of new technology. The job cannot be done by the Government alone and a wide range of interests will need to play a full and active part in the programme to ensure that the UK will be in a position to exploit the technologies both here and overseas.

2.3. It is felt appropriate therefore, for the Government to provide a focus for the support and development of cleaner coal technologies and to assess and promote ways of improving the economics of extraction techniques in the longer term. To do this effectively, the Government should examine very carefully research priorities, in partnership with industry.

Key principles of the strategy

2.4. The implementation of the proposed strategy will need to take full account of development overseas, where substantial research on cleaner coal technologies and mining techniques is underway. Some parallel work in research effort is inevitable, even desirable, to fully test new technologies. However, in terms of value for money for scarce R&D funds, buying-in appropriate technologies fully tested by overseas research programmes, and collaborative international projects via bilateral agreements, International

Energy Agency programmes and European Commission programmes, will play an important part of any UK long term strategy for cleaner coal technologies and mining developments. The buying-in of technologies developed from other government programmes may still however require further research to enable imported technologies to meet UK operational conditions, both in respect of mining technology where legislation and health and safety issues may need to be considered, and coal preparation and utilisation, where the properties and characteristics of UK coals may be different.

2.5. A fundamental part of the development of the Department's coal research strategy will need to be industrial involvement. Industry will need to play a full part in the strategy, both its initiation and development. While the Government should wish to see a growing financial contribution from British Coal and UK industry over the lifetime of the proposed strategy, particularly as technologies approach commercialisation, a key factor will be industry's technical involvement. This will ensure the programme is technically robust and firmly directed to meeting the future needs of industry in the winning and use of coal. It should be emphasised, however, that the Government's strategy should not cover all R&D undertaken by the energy supply industry to meet short/medium term business needs. This work is properly the responsibility of industry, with Government funds concentrated on high risk, long term research with national interest implications. **The Department's new coal programme should aim to provide a focus of UK activity on long term, coal-based research, in partnership with the energy supply and utilisation industries.**

Strategy

2.6. The terms of reference for the Department's review of its coal research programme were to produce a strategy which would act as a focus for UK research effort aimed at the continued exploitation and utilisation of coal in a safe, efficient, cost effective and environmentally acceptable manner. To this end, this proposed strategy aims to identify, assess and stimulate appropriate options for coal utilisation, preparation and exploitation. The plan would be reviewed on a continuing basis against changing threats and opportunities from competing energy sources and against changing environmental legislation.

2.7. The key strategic aims of a new proposed strategy for coal-based research programme supported by the Department would be:

- **for cleaner coal technologies, the aim is to ensure that there is a firm foundation for the exploitation of cleaner coal technologies in the UK for electricity generation and other industrial uses;**
- **for coal extraction technologies, the aim is to assess the feasibility and potential of novel extraction methods and practices, outside the scope of commercial activities,**

to enable indigenous coal resources to be exploited safely, economically and in an environmentally acceptable manner;

- **for coal preparation technologies, the aim is to assess and develop novel techniques, including those capable of handling ultra fine/ultra clean coals, to increase their market acceptability.**

In order to achieve these aims, the programme would support basic science and technology relevant to coal extraction, preparation and utilisation technologies, and the environmental impact of coal.

2.8. The criteria which will be used by the Coal Task Force to assess project proposals seeking funding under the programme are listed in Appendix 2.

Reviewing and monitoring

2.9. For each of the sectors in these key target areas, individual aims and objectives have been established as an integral part of the proposed strategy. These are listed in Appendix 1 and would be reviewed regularly on a programme area basis, as appropriate, throughout the planned timescale of the strategy. The first complete review of the whole programme is planned for 1993/94. These sector aims and objectives should ensure that the proposed strategy can be effectively monitored and the research portfolio developed in a cost effective and efficient manner. Individual sub-sectors may only require a limited amount of research and their objectives achievable within a limited timescale. Others, such as the assessment and demonstration of the Topping Cycle concept, may need about ten years to bring to commercial status.

2.10. The proposed strategy will also take appropriate account of the value of research into longer term insurance technologies such as coal liquefaction and pyrolysis. The Middle East crisis has highlighted the uncertainty of continued stability in the supply and production of oil. The Department is currently supporting major projects on pyrolysis and coal liquefaction and when the present work programme is completed, will review future work with other participants in this collaborative research.

Cleaner coal technology development

2.11. **Cleaner coal technologies, for the purposes of this proposed strategy, are technologies which provide methods of preparing, utilising and exploiting coal in the most efficient and environmentally acceptable ways. These include all new high efficiency low pollution combustion/conversion systems such as IGCC and PFBC, together with coal liquefaction technologies.**

2.12. The development of cleaner coal technologies is a crucial part of the proposed strategy and would encompass both the acid rain precursors and CO_2. In particular, the proposed strategy would explore the potential for CO_2 reduction, particularly by examining technologies which offer prospect of improved levels of overall conversion efficiency. It is already clear that a few key technologies would form an important part of the proposed strategy. These include the development of combined cycle technology, including the Topping Cycle, Integrated Gasification Combined Cycle (IGCC) and gasification supplying a humid air turbine. Over the past ten years a considerable amount of research effort has been devoted to developing a number of these advanced power generation systems.

Table 7.1 in Appendix 1 summarises their present state of development, together with the potential advantages and disadvantages of these technologies.

2.13. In order to meet the proposed objectives of establishing demonstrated technologies early in the next century, prototype commercial plants would need to be available for assessment from the mid 1990s. Some of these plants are already being constructed or are at the planning stage in Europe, Japan and the United States, and information as to their economics and efficiency would make a valuable input to the programme, perhaps leading to the first such plant in the UK. In other cases, such as British Coal's Topping Cycle concept, UK-based work may be appropriate.

Timescales

2.14. The development of new coal-based technologies is a long term undertaking. An effective research strategy would need to cover around a ten year period to allow for the appropriate level of research, development and vital technology transfer to take place. Some technologies are already well advanced, but others may take longer to reach fruition. Radical new extraction technologies, such as underground coal gasification, will require a much longer development period if confidence in the technology, both economic and environmental, is to be achieved. Priorities for research would take account of these "long-shot" technologies, having appropriate regard to opportunities for international collaboration and their insurance value.

2.15. Following an evaluation phase (2-5 years), the intention would be to move the most promising of the advanced technologies towards the commercial market place by ensuring appropriate technology transfer. The evaluation stages would incorporate substantial research activities, particularly where small scale plant can be used to prove economic and environmental acceptability. In order to stimulate the commercial uptake of a technology, work would need to be undertaken at a scale large enough to enable industry to judge commercial potential and make informed and confident decisions concerning the future economic and environmental impact of the technologies. A similar approach would be adopted for any technology transfer activities for coal preparation technologies and advanced extraction techniques.

Phasing

2.16. The phasing of the proposed strategy would be as follows:

1st phase: 1991-1995/96

- an appraisal and development of cleaner coal technologies felt to be appropriate to UK conditions;
- research to improve the economics and geological risk of coal winning;
- an appraisal of novel coal preparation, transport and handling technologies;
- research activities related to retrofit utilisation technologies.

Appropriate R&D would be initiated as required during this period when research priorities and needs have been clarified and agreed.

Major reviews of programme areas would be undertaken, as appropriate, between the 1st and 2nd phases.

2nd phase: 1993/94-2000/01

- demonstration phase of advanced cleaner coal technologies and related technology transfer activities;
- research and development to assess the potential of novel extraction techniques;
- demonstration phase of promising novel coal preparation processes;
- technology transfer of the results of research activities related to retrofit utilisation technologies.

2.17. The proposed phasing is not rigid and there would be some degree of overlap between the two phases. If the research activities were successful in phase 1, there should be some flexibility in bringing forward phase 2 work, subject to other priorities and the availability of funding.

Expenditure

2.18. For each of the main sectors listed in Appendix 1, an assessment of the likely cost (1990 cost levels) of the research, development and demonstration to meet the targets set for the individual sectors is presented. **These costs can only be rough estimates at present. No attempt has therefore been made to split these rough estimates between the Department, industry and other funding sources.** The balance of funding in the various sectors would be considered against the criteria referred to in Appendix 2.

There are of course many uncertainties yet to be resolved; these could affect the picture significantly and changes must be expected as further results from the RD&D, programme become available. The figures give the total costs of the RD&D, rather than that from Government; the resources needed for each sector from the Department would have to be decided at the appropriate time, as part of the Government expenditure cycle, following negotiation with industry and other organisations on their financial contributions.

2.19. The international nature of RD&D in the energy field means that overseas governments and international organisations, such as the European Commission and the International Energy Agency, would be involved in the proposed future programme to a greater extent than at the present. A number of collaborative projects with these organisations have recently been initiated. The split between UK Government, industry and other funding sources, would vary in percentage terms depending on the closeness of individual technologies to the market place. The Government would expect a growing industrial contribution as the technologies approach commercialisation, commensurate with the rewards of successful technology transfer.

2.20. **As a target for the programme as a whole, the Department will wish to maintain the ratio of external contributions (both industry and other funding agencies - UK and overseas) to its own contribution in excess of 4:1, although the ratio may well vary from project to project. The Department should recognise that for some UK based projects, such as taking cleaner coal technologies to the demonstration phase, a higher level of Government support would be necessary. In others, such as buying into overseas demonstration projects, a lower level of funding would be required to ensure the UK gains access to the technology.**

3. ENVIRONMENTAL AND SAFETY FACTORS

3.1. The Government attaches great importance to assessing the environmental and safety implications associated with development of new coal technologies. In the White Paper on the Environment, "This Common Inheritance", published in 1990 (HMSO), the Government recognised it has a leading role in developing sensible and sound policies for the environment.

3.2. One of the main aims of the proposed strategy outlined in this document would be to ensure the environmental impact of coal winning and use can meet future environmental controls and therefore contribute to the overall aims of the Environment White Paper.

3.3. As with all issues relating to the coal mining industry, the Department attaches great importance to ensuring all of its research activities take full account of health and safety. The Health and Safety Executive would be kept informed of the development of the new programme and, where appropriate, specific health and safety research would be initiated, such as the impact of new extraction techniques, and waste materials from advanced combustion technologies.

3.4. Details of environmental aspects and emission abatement, including current and likely future legislation associated with emission levels, is included in Section 2 of Appendix 1.

4. INSTITUTIONAL FACTORS (COLLABORATION AND AWARENESS)

4.1. The completion of successful research on developing coal technologies, reducing the uncertainty about their technical performance and their costs, will not necessarily lead to successful commercial exploitation. There are many institutional barriers which inhibit the exploitation of some technologies which might on all other counts, appear attractive.

4.2. As a key part of this proposed strategy, the Government should intend to work for the removal of these barriers wherever necessary, in order to allow the investment in scarce research funds to be effectively utilised and offer the best value for money. The principal means of achieving this would be stimulating collaborations and creating a greater awareness of technical options.

Collaboration on cleaner coal technologies

4.3. Before it can make commercial decisions concerning advanced power generation plant, industry requires confidence in the technical performance of such plant. This can only be achieved by successful demonstration of the technology at an appropriately large scale, and, in most cases, individual industrial companies are unable to carry the high costs and risks associated with large experimental or demonstration plants. Exposure to these costs and risks can be reduced by collaborative effort and thereby enable industry to participate in demonstration projects that would not otherwise take place. Through participation in such collaboration, industry should be able to make more informed commercial decisions about purchasing advanced power generation plant.

4.4. The Government should support and play a full part in collaborative arrangements between UK industry to stimulate cleaner coal technology development. This would be accomplished in the first instance by establishing Working Groups with the remit to investigate the most effective way of getting cleaner coal technologies taken up by UK industry. The Working Groups would be used to explore the most appropriate funding mechanisms to construct the first UK plants for these technologies. The first of these Working Groups on IGCC technology has already been established. In some cases, buying into overseas demonstration activities may be a cost effective way to improve UK expertise and know-how about such technologies. In such circumstances, the Working Groups would be used to establish consortia of interested parties to collaborate in international projects when it is worthwhile to do so.

4.5. The European Community's THERMIE programme offers considerable potential for UK industry to collaborate with the Commission and overseas industry in developing cleaner coal technologies. The Department should, therefore, consider putting more resources into developing collaborative projects under the auspices of the THERMIE programme.

4.6. The Department should recognise that industry and universities pursue, and will continue to pursue, coal research and demonstration activities to meet their own objectives. These activities make a useful contribution to the knowledge base in relation to coal technology. In recognition of this contribution, the Department should put more resources into assisting UK industry and universities in submitting coal technology proposals for European Community funding under the Framework programme (JOULE) and under the THERMIE demonstration scheme. This would include issuing more detailed guidance notes to potential applicants and assistance on individual proposals. The Department already issues general guidance notes about Community programmes, circulates copies of Calls, distributes application forms and advises potential proposers. A number of seminars are also held in various centres around the UK aimed at encouraging UK participation on the Community programmes.

Awareness

4.7. As an integral part of its coal programme, the Department should provide accurate information to all interested parties both on the results of its own research programme and developments overseas. Technical workshops would be organised as part of the technology transfer initiatives associated with the programme, both to impart the results of successful research and to obtain feedback on further research needs. Publication and widespread dissemination of Project Profiles/Summaries and Reports would be undertaken, drawing on the valuable experience gained by the Department through its Renewable Energy and Energy Efficiency programmes.

5. FUTURE ACTIONS

5.1. This paper has identified the necessary research that is required over the next ten years, in collaboration with UK industry and overseas organisations, to ensure that coal remains a key energy option for the 21st century. It has also outlined a number of initiatives aimed at developing and enhancing collaborative activities between industry and Government. The Government has already shown its commitment through recent announcements including:

- additional financial support for British Coal's Topping Cycle project, bringing the Department's contribution to over £9 million;
- a collaborative £17 million project on underground coal gasification with the European Community;
- a £10 million collaborative project on high temperature/ high pressure filters with the International Energy Agency;
- a £1.85 million collaborative project on coal flame research with the International Energy Agency;
- a £1.6 million collaborative project with the International Energy Agency for a co-operative programme for technologies relating to carbon dioxide removal, utilisation and disposal.

5.2. The ongoing projects have been funded at a total cost to Government of nearly £18 million, with a total project value in excess of £88 million. Other contributions are split more or less equally between UK industry and overseas organisations.

5.3. The Department of Energy should use this paper to invite increasing participation by industry in the Government sponsored coal technology research, development and demonstration programme.

APPENDIX 1

STRATEGIC SECTORS AND RESEARCH, DEVELOPMENT AND DEMONSTRATION OPPORTUNITIES

APPENDIX 1

STRATEGIC SECTORS AND RESEARCH, DEVELOPMENT AND DEMONSTRATION OPPORTUNITIES

1. INTRODUCTION

This Appendix reviews the main sectors encompassed by the coal extraction and utilisation cycle that would be targeted by the Coal R&D programme. These sectors cover both "cleaner coal technologies" (ie, technologies which provide methods of preparing, utilising and exploiting coal in the most efficient and environmentally acceptable ways), and coal exploration and extraction. "Extraction" is used since the coal may ultimately not be physically mined, but rather converted in-situ and its energy content extracted in a different physical state.

The "coal cycle" can be considered as five main activities, namely:

- coal exploration and extraction;
- coal preparation;
- coal handling and supply;
- coal conversion, if applicable;
- coal (or secondary product) utilisation.

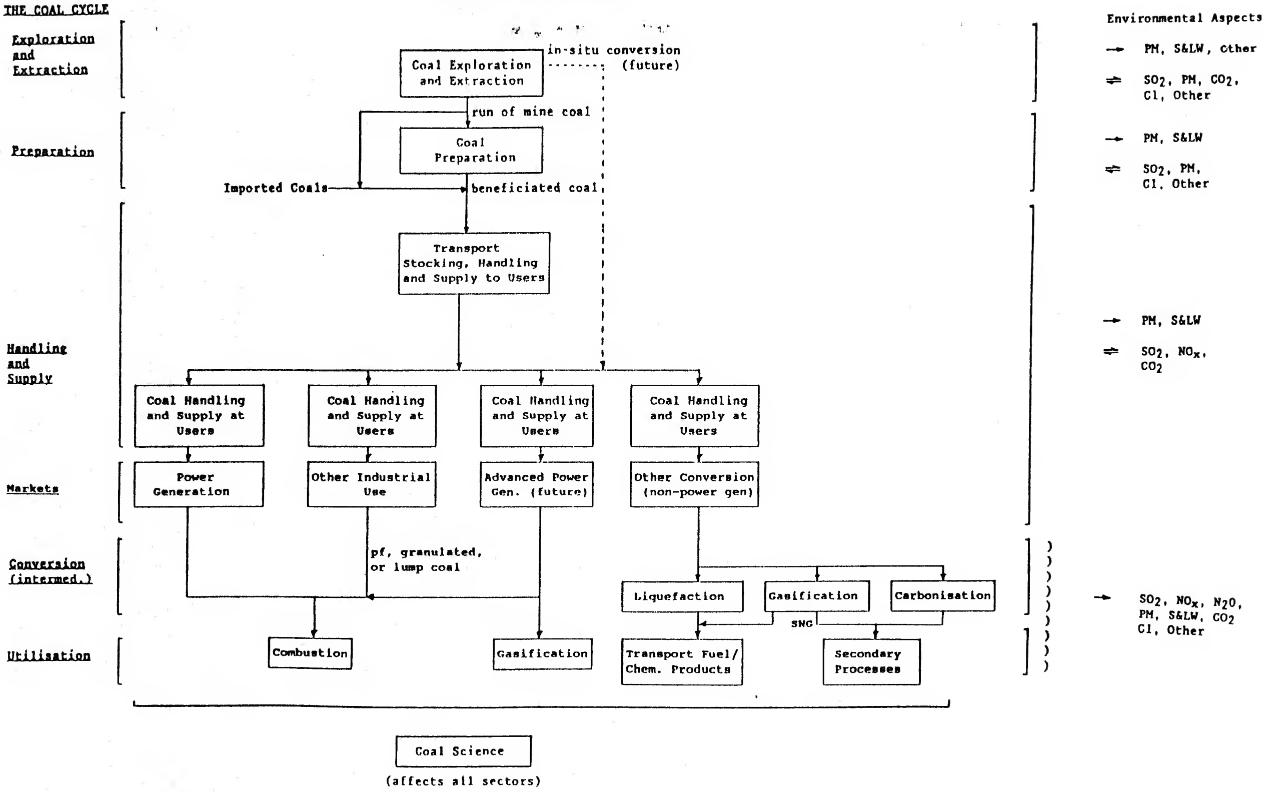
Traditionally, utilisation has involved combustion for power generation or other heating/steam raising purposes, or conversion into a secondary product (eg, gas or coke). The domestic use of coal does not come within the scope of this proposed strategy.

The five activities which can be considered to constitute the coal cycle are highly interactive and the whole cycle needs to be considered as a "system". The optimising of this whole system requires not just the efficiency and cost effectiveness of the ultimate utilisation of the coal to be considered, but also environmental concerns, including byproducts and waste products from each component activity. The Coal Task Force will be keen to link together successful R&D from the five main activities to form new systems to be applied to the coal cycle.

Whilst considerable commonality exists between conventional combustion for power generation and other industrial purposes, more environmentally acceptable advanced power generation systems are emerging. These are based on sophisticated pulverised fuel boilers, fluidised bed combustion, coal gasification technology and combined cycle operations. Such systems offer higher efficiency and lower pollution levels than conventional combustion technologies and therefore need to be examined separately.

Although coal gasification to produce fuel gas for advanced power generation systems is a coal conversion technology, this gasification process is an integral part of the final utilisation of

FIGURE 1: THE COAL CYCLE


THE COAL CYCLE
Exploration and Extraction
Preparation
Handling and Supply
Markets
Conversion (intermed.)
Utilisation
Coal Exploration and Extraction
in-situ conversion (future)
run of mine coal
Coal Preparation
Imported Coals
beneficiated coal
Transport Stocking, Handling and Supply to Users
Coal Handling and Supply at Users
Coal Handling and Supply at Users
Coal Handling and Supply at Users
Coal Handling and Supply at Users
Power Generation
Other Industrial Use
Advanced Power Gen. (future)
Other Conversion (non-power gen)
pf, granulated, or lump coal
Liquefaction
Gasification
Carbonisation
SNG
Combustion
Gasification
Transport Fuel/ Chem. Products
Secondary Processes
Coal Science
(affects all sectors)
Environmental Aspects
→ PM, S&LW, other
⇌ SO2, PM, CO2, Cl, Other
→ PM, S&LW
⇌ SO2, PM, Cl, Other
→ PM, S&LW
⇌ SO2, NOx, CO2
→ SO2, NOx, N2O, PM, S&LW, CO2 Cl, Other

KEY: → indicates a direct environmental emission

⇌ indicates an indirect environmental impact on subsequent stages of the cycle

SO_2 (sulphur dioxide); NO_x (nitric oxide and nitrogen dioxide); N_2O (nitrous oxide); PM (particulate matter); S&LW (solid and liquid wastes); CO_2 (carbon dioxide); Cl (Chlorine); Other (other emissions, ie, methane, toxic hydrocarbons, dioxins etc) the coal. It is therefore distinct from some other conversion technologies that create a secondary product for utilisation in a different market, eg, coal gasification to produce Substitute Natural Gas (SNG), coal liquefaction to produce transportation fuel and coal carbonisation to produce coke for say, the steel industry.

In addition, coal science cannot be excluded, since the impact of coal quality on different processes and the environment is not sufficiently understood to allow detailed economic assessment for the use of a particular coal. This is being addressed through a study currently underway with Battelle Inc. in the USA.

For the purpose of this strategy, therefore, seven sectors are identified within the coal cycle, namely:

- coal exploration and extraction;
- coal preparation;
- coal handling and supply (both at the source and market location);
- coal combustion processes (power generation and industrial uses);
- advanced power generation;
- other coal conversion and utilisation processes;
- coal science.

The interrelationship of these sectors within the coal cycle is illustrated in Figure 1, which also shows the direct and indirect environmental impact of different stages in the cycle. Indeed, environmental aspects pervade the cycle and as can be seen, many different parts of the cycle may have a bearing on one or more environmental concern. For example, emissions of sulphur dioxide (SO_2) are only produced at the point of combustion or conversion, but considerable scope exists in many of the "upstream" processes to limit the final level of SO_2 emission. A matrix of the influence of different parts of the coal cycle on different emissions or waste products can be drawn up, and this is illustrated in Figure 2. The environmental concerns considered in this matrix are:

- sulphur dioxide (SO_2);
- nitrogen oxides (ie, NO_2, NO and N_2O);
- particulate matter (PM);
- solid and liquid wastes (S&LW);
- carbon dioxide (CO_2);
- chlorine (Cl);
- others (including methane and other hydrocarbons).

It is recognised that the interaction is complex between these environmental concerns and each of the parts of the coal cycle. Thus for the sake of clarity, this Appendix is divided into modules, with the environmental concerns discussed first, followed by discussions on each of the seven identified sectors.

	ENVIRONMENTAL CONCERNS						
THE COAL CYCLE STAGES	SO_2	NO_x	PM	S&LW	CO_2	Cl	OTHER
Coal Exploration & Extraction	(*)		*	*	(*)	(*)	*
Coal Preparation	(*)		*	*		(*)	(*)
Coal Handling & Supply	(*)	(*)	*	*	(*)		
Coal Combustion Processes	*	*	*	*	*	*	*
Advanced Power Generation	*	*	*	*	*	*	*
Other Coal Conversion Processes	*	*	*	*	*	*	*
Coal Science	(*)	(*)	(*)	(*)	(*)	(*)	(*)

(Note: a bracketed asterisk indicates an indirect bearing on the emission at the point of production)

FIGURE 2: **THE ENVIRONMENTAL IMPACT OF ELEMENTS OF THE COAL CYCLE**

Structure of Appendix

Each module is set out in a similar format, commencing with paragraphs setting out:

- The **Aim** and **Rationale** of RD&D in that sector;
- Its **Objectives**;
- The **Total Estimated Cost of an RD&D Programme** (including the Department of Energy's contribution) to achieve those objectives;
- A **Summary** of the module.

The remainder of the module sets the scene, discusses the current state of R&D and proposes the future requirements for RD&D, giving illustrative rather than prescriptive examples.

The timescale considered in this proposed strategy is ten years, this being the minimum period to allow for the appropriate level of R&D and technology transfer.

Health and safety issues are of paramount importance. Whilst not necessarily explicitly mentioned in the remaining modules of the Appendix, it is axiomatic in the discussion of RD&D opportunities that the health and safety of operatives and of the public will not be detrimentally affected by any project undertaken. Where these concerns are of particular relevance, for example, in extraction operations and chemical processing type environments, health and safety aspects are discussed explicitly.

As indicated in the Summary of this proposed strategy, the main priority is to ensure that advanced, cleaner technologies are available in the UK by the end of the decade to enable coal to achieve its full economic potential in the energy market. It is expected that at least two-thirds of the overall cost of the programme would be spent on cleaner coal technologies, with the remainder on the coal supply technologies. The total estimated costs of the identified RD&D programmes for each of the modules are presented in Table 1.1, in priority order.

Table 1.1

Summary of the Total Estimated Cost (including Govt. Contributions) of RD&D Programme Modules

Module	Estimated Cost
Advanced power generation	£250-600 million
Other coal conversion and utilisation processes	£50-100 million
Coal combustion processes	£15-25 million
Coal handling and supply	£10-15 million
Coal science	£5-10 million
Coal exploration and extraction	£40-60 million
Coal preparation	£7-10 million

Note: The broad range of the total estimated costs for the first two programme modules reflects the degree of uncertainty regarding the number of technologies taken forward to demonstration scale. This will be reviewed between the first and second phases of the programme.

2. ENVIRONMENTAL ASPECTS AND EMISSION ABATEMENT

The utilisation of coal for utility, industrial/commercial and domestic use has been affected greatly in the last decade by a number of factors - the cost and availability of competing fuels, changes in the regulatory climate affecting the electricity supply industry, and changes in environmental regulations. Arguably, the most important of these changes has been the tightening of standards for the discharge of airborne pollutants and solid wastes, particularly from power generation utilities.

Growing international interest and concern for the protection of the environment has been matched by steadily increasing pressure to introduce or tighten existing legislative controls on industrial activity. Of particular concern are gaseous emissions potentially contributing to global warming (carbon dioxide, methane, nitrous oxide etc), acid gas emissions (sulphur dioxide, oxides of nitrogen and chlorine), particulate matter, solid and liquid wastes (from mining activity, coal preparation, combustion/conversion and flue gas desulphurisation) and toxic hydrocarbons (PCBs, dioxins etc).

As a significant source of carbon dioxide, the combustion of coal for power generation purposes has come under increasing scrutiny. This has prompted considerable research, development and demonstration of cleaner coal technologies, offering enhanced overall conversion efficiencies and hence lower specific carbon dioxide emissions.

Pressure for legislative control of acid gas emissions culminated within the European Community with the development of a "Framework for Action" and then, in June 1988, with an agreement on a Directive on "The Limitation of Emission of Pollutants into the Air from Large Combustion Plants" (EC Directive 88/609/EEC). This Large Combustion Plant (LCP) Directive was formally adopted in November 1988 and has the effect of bringing standards for new facilities (over 50 MW(th), authorised after 1 July 1987), among its member states to a minimum level of uniformity. Emission limit values for sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and particulate matter (PM) are set for all new plants throughout EC member countries. The Directive also sets overall objectives for existing plants (over 50 MW(th)), for a gradual and staged reduction of total annual emissions of SO_2 and NO_x. The target percentage reductions are country specific and will be considered under each of the emissions covered later in this section.

Emission standards usually take due consideration of the availability and cost of cleaner technologies and control measures and are consequently often referred to as "technology standards". Despite this, these standards do not actually prescribe a particular technology but specify instead the use of "Best Available Technology" (BAT) or, as is currently the case in the UK, "Best Practicable Means" (BPM). BAT or BPM standards can be more or less stringent than emission standards, depending upon the interpretation of the legislative language. For example, in the UK there were until recently no specific air emission standards but rather a requirement for the use of BPM control technologies taking account of available technology cost, locality and potential environmental impact. Currently, all OECD countries have established emission limits for new large combustion facilities for the major air pollutants (ie, SO_2, NO_x and PM).

In the UK, new BPM notes were introduced in 1988 for new plants over 500 MW(th). In effect, these notes require all new plant over this size to be fitted with NO_x control (eg. low NO_x burners) and SO_2 abatement systems (eg. FGD). These limits are currently being brought into line with the other requirements of the LCP Directive. It is anticipated that the emphasis on UK standards will be altered from a BPM approach to a "Best Available Technology Not Entailing Excessive Cost" (BATNEEC) approach. This is currently being addressed through a submission to the CEC on the mechanism for achieving the requirements of the LCP Directive.

The details of the target percentage reductions required of the UK and the technologies for achieving these targets are examined below for each of the pollutants. R&D activities and further requirements for R&D are described in the briefest of detail, the specific areas for R&D being covered in more detail in subsequent sections of this Appendix.

2.1 Sulphur Dioxide (SO_2)

As a signatory to the LCP Directive, the UK is committed to reducing its SO_2 emissions. Since coal-fired power stations are the largest source, accounting for 71% of the 3 million tonnes of SO_2 released in the UK in 1988, they must be expected to make a major contribution to achieving the targets specified under the Directive.

Although the largest producer of SO_2 in Western Europe, the UK faces less stringent emission targets than other European countries due to the high sulphur content of UK coals (1.6% average). The LCP Directive requires emissions from all types of plant in the UK to be reduced in three stages, relative to a 1980 baseline: 20% reduction by 1993, 40% by 1998 and 60% by 2003. This compares with a target 70% reduction by 2003 in West Germany, the Netherlands, France and Belgium.

In 1987, prior to the agreement on the LCP Directive, the CEGB announced its intention to retrofit Flue Gas Desulphurisation (FGD) to 6,000 MW(e) of coal fired boiler plant capacity, to ensure that the existing levels of SO_2 emissions would not increase in the future. At the same time, it was proposed that all new plant should be fitted with FGD. Agreement of the LCP Directive meant that additional FGD capacity would need to be retrofitted, although obviously this was sensitive to the degree to which alternative options could be applied; for example the use of low sulphur imported coal or natural gas to replace existing fuels. The CEGB consequently doubled its proposed FGD programme to encompass 12,000 MW(e) of power station plant.

The cost of retrofitting FGD led to a total estimated cost of £2 billion for the 12,000 MW(e) programme. As a result of commercial considerations, allied to the imminent privatisation of the industry, the 12,000 MW(e) target was reduced to 8,000 MW(e) in April 1990, with a projected cost saving of £800 million. This does not preclude, a greater target being set at a later date.

This relaxing of the requirement for FGD to achieve the reduction targets under the LCP Directive, opens the way for using low-sulphur coal imports, natural gas, etc. It also demands that attention be given to other ways of reducing SO_2 emissions.

A variety of technical options for reducing SO_2 emissions exist, at various stages of commercial availability. These options broadly divide into pre-combustion, during combustion and post-combustion techniques.

- Pre-combustion

- coal extraction/blending to minimise sulphur content;

- reducing pyritic and possibly organic sulphur during coal preparation;

- reducing pyritic sulphur during milling to make pulverised fuel (pf) at the power station.

- During combustion

- direct injection of limestone or dolomite as a sorbent in a fluidised bed combustor enables removal of sulphur as calcium sulphate. Also calcium hydroxide addition may be considered (dependant on cheap source);

- Post-combustion (Flue Gas Desulphurisation)

  A large number of different technologies are available, the more widely used being:

- Spray Dry FGD (a slurry of lime, limestone, sodium carbonate or bicarbonate is atomised and sprayed concurrently over the hot flue gas stream, drying in the hot gases, to be collected in the bag filters);

- "once through" wet scrubbing FGD using the limestone to gypsum process (eg, Drax);

- "regenerative" FGD, eg, the United Engineering process (magnesium based) and the Wellman-Lord process (sodium based).

Some techniques associated with the during- and post-combustion options are commercially available, with reference plants already operating. Nevertheless, scope exists for R&D in the areas of waste disposal (both solid and liquid), optimising the processes from chemical engineering and economic points of view, and novel cheaper techniques.

However, limiting sulphur emissions by reducing the sulphur content of coals prior to combustion relies on technologies which are, by and large, at the experimental stage or currently undergoing development. One of the major areas of interest at present is the minimisation of pyritic sulphur and organic sulphur content at the coal preparation stage using physical, chemical or biological means.

Physical techniques for desulphurisation during coal preparation include two stage froth flotation (in which a primary froth with substantial quantities of pyrite is refloated to produce a cleaner final product), spiral concentrators and high gradient magnetic separation (using a magnetised matrix to entrap weakly paramagnetic materials, eg pyrite).

Coal preparation processes which will desulphurise coal by chemical means are currently being developed in a number of countries. These processes, which involve coal particles being cleaned by hot solutions of chemicals are generally under development on a laboratory or small pilot plant scale. Some of these processes combine a sulphur removing first stage with a second stage treatment to remove most of the mineral matter. Removal of up to 90% of the pyritic sulphur and 75% of the organic sulphur is considered possible, but chemical cleaning alone is unlikely to enable coal to meet the LCP Directive.

The microbial desulphurisation of coal using a range of iron and sulphur oxidising micro-organisms has been the subject of an EC collaborative R&D project supported by DG XII. Building on the success of this project, the CEC is eager to support further work leading to pilot-scale studies.

2.2 Nitrogen Oxides (NO_x and N_2O)

The oxides of nitrogen, produced in the combustion process from the nitrogen in the fuel and the thermal reaction of the nitrogen in the air, comprise mainly nitric oxide (NO) and nitrogen dioxide (NO_2). These components, together referred to as "NO_x", are relatively easy to measure. However, a third oxide, nitrous oxide (N_2O) is also produced during combustion and this is becoming of increasing interest as it is a significant contributor to global warming (6% contribution during the 1980's and increasing). This is primarily because nitrous oxide is a relatively inert gas in terms of atmospheric chemistry, which prolongs its lifetime. Nitrous oxide has also been notoriously hard to measure, due to continuing reactions of other flue gas constituents in collected samples. This has led to erroneously high measurements in the past. These difficulties have caused nitrous oxide to be excluded to date from the regulated "NO_x" gases; a situation that may not prevail in the long-term.

The limits for NO_x emissions in the UK as set out in the LCP Directive are as follows:

New coal fired plant - < 650 mg/Nm^3 or 390 ppm (dry basis) @ 6% O_2.

Existing plant - 15% reduction to be achieved by 1993 (30% by 1998) from 1980 levels.

In the UK plans were drawn up by the CEGB, prior to privatisation, to install low NO_x burners on the twelve largest power stations, comprising 24,000 MW(e) of generating capacity. This approach is proving to be successful due to the characteristics of British coal. Whilst this approach ensures that the UK complies with the current EC directive, it is likely that future emission limits will be tightened. Japan in particular, and the USA have achieved lower NO_x emission levels by adopting a furnace staging approach in combination with low NO_x burners. Furnace staging is an approach that may not be suitable for all UK power generation boilers; fuel staging in the burners is another possibility. Reburn and optimising fuel air mixtures (eg, through dense phase supply systems) also require attention. Other approaches, albeit more expensive, to reducing NO_x are also possible: Selective non-catalytic reduction (SNCR) selective catalytic reduction (SCR) and various absorption processes. Such processes may be needed when and if NO_x emission limits are reduced still further. At present these processes are not considered to be cost effective. Where a furnace staging approach might cost £2-3M for retrofit to an existing 500 MW boiler, the SCR route for an equivalent boiler would cost £23 M and would also increase annual operating costs by over £5 M, although these costs appear to be falling rapidly.

In the near term it is likely that furnace staging in combination with improved low NO_x burners will be needed for all pf boilers to meet tighter emission limits. Although some information exists on NO_x emissions associated with the staged combustion of British coals, research needs to be undertaken to optimise abatement by this method. At the same time, it is recognised that more stringent limits on NO_x emissions may well be introduced. Whilst this can be achieved through the application of SCR and SNCR technologies, it is possible that other solutions, such as further improvements to low NO_x burner design, could be found. These could be proposed as a result of improved understanding of NO_x formation mechanisms, thereby allowing combustion systems to be developed that further reduce NO_x formation.

Should emission limits be tightened to the extent that SNCR and SCR processes prove necessary, RD&D will be necessary, addressing process fundamentals. This RD&D will be aimed at improving the understanding and application of these technologies leading on to demonstration to prove their viability in UK boilers and with UK coals. Whilst SCR is commercially utilised overseas (albeit at considerable cost), SNCR is not yet a viable technology for large UK boilers. The CEGB's successor companies are however, interested in any future developments.

Emissions of nitrous oxide (N_2O) are not well understood at present, due mainly to problems in its detection and measurement. It is believed that the important kinetic reaction "pathways" to its formation involve nitric oxide and fuel hydrocarbons. Recent data indicate emission factors in the range 3-10 g (nitrogen)/GJ. There are some indications that the reaction may be preferred at lower temperatures typical of fluidised bed combustion. If N_2O abatement does become an issue, attention will likely focus on fluidised bed combustion technologies.

2.3 Particulate Matter (PM)

The methods for removing particulates (fly ash) from boiler flues are well established. There are four main methods for fly ash removal: cyclones, fabric filters (FF), electrostatic precipitation (ESP) and wet scrubbing. ESP is used primarily in the ESI, although based on US experience, is likely that FF technology will be adopted within the next decade. There is ongoing research into improving collection efficiency by use of new materials, enhancing ESP performance through change in design parameters and combining different systems. Studies on re-entrainment processes in ESP systems are important, as significant emissions can result. Optimisation of particle charging techniques could also lead to efficiency gains in ESP performance.

As new coal utilisation technologies are developed such as FBC and IGCC and various de-SO_x/de-NO_x technologies are applied, there will be a need to undertake development of systems that will remove fly ash with equivalent or better efficiencies than presently achieved. Systems are being developed, such as the "$SO_xNO_xRO_xBO_x$" of Babcock & Wilcox, which are designed to remove sulphur oxides, nitrogen oxides and particulates from the flue gases in one device. Studies will be needed that look at the application of such systems and the implications (cost, waste, efficiency etc), for their use.

2.4 Solid/Liquid Wastes

The extraction and subsequent use of coal gives rise to the production of solid and liquid wastes. There are already established ways of dealing with these wastes, but the management of these waste products has generally proceeded in an unstructured manner with levels of responsibility poorly defined. However, greater environmental awareness has and will result in a need to investigate and apply technologies for improved handling and disposal of wastes.

Waste disposal is now covered by the EC Directive of June 1988 which requires an Environmental Assessment (EA) for certain large projects (EC 85/337). These projects include thermal power stations with a thermal output of 300 MW+, industrial installations for energy production and installations for the disposal of industrial and domestic waste. Landfills are likely to be the major form of waste disposal, but they are currently a focus for environmental concern over the risk of pollution from methane gas, poor fill stability resulting in health and safety hazards, and ground and surface water pollution from contaminated leachate and runoff.

Further, the introduction of new combustion systems (AFBC, PFBC) and pollution abatement technologies (SCR, SNCR, FGD) will change and increase the quantities of residues associated with coal utilisation. Work is currently progressing on the utilisation and disposal of residues, simultaneously assessing the associated environmental impact. It is likely that more stringent legislation will be introduced by the EEC and at a national level. This will require more detailed analysis of waste residues associated with the many and alternative process routes, together with their behaviour associated with different disposal routes. Greater emphasis is also likely to be given to ways of recycling the residues and possible adjustment of the nature of the ash, not least because of the likelihood of decreased availability of disposal sites and increased disposal costs.

Advanced waste water treatment processes, including ultrafine filtration, membrane separation and dissolved air flotation processes, may well enable effluent levels to be reduced to such an extent that recycling of cleaned water effectively reduces the liquid effluent discharge to zero. Technical problems still persist with all these technologies, and R&D will be needed to overcome these. Water transport mechanisms also require greater understanding, since these are fundamental to the propagation of any contamination

2.5 Carbon Dioxide (CO_2)

International concern, coupled with the prominence given in the media to the "Greenhouse Effect" and global warming, will likely result in the production of CO_2 from fossil fuel combustion being a major environmental issue of continuing importance. An Intergovernmental Panel on Climate Change (IPCC) was recently set up under the auspices of the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO). The IPCC's remit is to develop collaborative analysis on all aspects of climate change, this being a necessary pre-condition to the development of any international agreement on greenhouse gases. In addition, the UK Government has developed and published an environmental strategy - "Our Common Inheritance". It calls on Government, industry and the individual to work in partnership to be stewards of our environment.

Until an international agreement is reached, it is difficult to determine what resources are needed and in what areas research needs to be undertaken in order to minimise the environmental impact of CO_2 emissions. Likely areas are the development of processes that minimise CO_2 release to atmosphere (eg, more efficient advanced power generation systems) and means of CO_2 abatement/disposal. What is certain however, is that the global nature of the problem will require any R&D to be of an international collaborative nature.

In this context, a cooperative programme of CO_2-related R&D has been proposed under the auspices of the IEA, which will hopefully involve 14 countries. This programme will be supported by the UK under the Coal R&D programme and British Coal will be the Operating Agent. The first Task of this programme is to evaluate (on a full fuel cycle basis), the technical and economic feasibility, technical performance and environmental benefits/impacts of technologies for removing, utilising, transporting and disposing of CO_2 produced in fossil fuel-fired power generation, relative to other options for reducing CO_2 emissions. This will lead on to estimates of the energy market and economic impacts of implementing potential abatement options, and the preparation of development and demonstration proposals for the favoured technical options showing economic promise.

2.6 Chlorine (Cl)

The influence of chlorine in coal on combustion performance is of particular significance in considering the use of British coals. Not only is chlorine present in the majority of coal mined in the UK (currently averaging 0.3-0.4% but up to 0.75%), but also the quantity increases with increasing depth.

While hydrogen chloride is present in power station stack emissions, the major concern to the generators is associated with fouling and corrosion (and associated costs) within the boiler. The alkalis associated with the chlorine typically combine with various trace metals to form alkali metal salts. However, there is some evidence to suggest that increasing sulphur-to-chlorine ratios can result in lower corrosion levels. In recognition of the considerable additional costs incurred by the generators in burning high chlorine coals, there is an agreed discount arrangement with British Coal for purchasing coals with a chlorine content greater than 0.35%.

A better understanding of chlorine's influence not just on combustion but also other coal utilisation technologies is required in order to quantify better its effects. Exploration of the different options that can be used to minimise chlorine's impact on coal utilisation is also urgently needed. This is discussed further under coal preparation and conventional coal combustion.

2.7 Methane

Methane ("firedamp"), trapped in coal measures during the coal formation process, is liberated during the mining of coal. Released methane must be diluted with ventilation air to avoid the formation of explosive (5-15% CH_4), or asphyxiating mixtures. In view of these safety implications, technology has been developed to drain off seam gas from the strata and to remove it by pipelines either directly to surface (for venting or utilisation) or to larger better ventilated roadways in the mine. It is estimated that coal mining in the UK accounts for approximately 27% of the total UK methane emission. Since methane is a major "greenhouse gas", contributing 18% to committed global warming over the last decade, interest in methane collection, concentration and utilisation is increasing, as is interest in methane drainage distinct from mining operations and underground coal gasification, which would combine the methane with a medium calorific value gas.

2.8 Other Emissions

Increasing environmental awareness will most likely lead to the need for more detailed analysis and records of stack emissions. As new techniques/technologies are introduced to improve process operations and reduced NO_x and SO_x emissions, it is possible that they will give rise to increased emissions of very fine particulates, poly-aromatic hydrocarbons, radioactivity, heavy metals, toxic hydrocarbons and dioxins. These latter two toxic emissions, together with PCB's, could be significant in processes where coal is simultaneously utilised with waste.

Consequently, there is a need to gain a better understanding of the effects of the various process routes (combustion, carbonisation, pyrolysis etc.) on the levels of all associated emissions. At the same time, it will be necessary to develop improved flue gas sampling techniques and associated monitoring equipment.

3. COAL EXPLORATION AND EXTRACTION

Aim: To assess, develop and promote selected options to improve product quality and productivity for existing mining methods and develop new extraction technologies which could be used to maximise the exploitation of the UK coal resource.

Rationale: To enable coal production to achieve its full potential in the energy market, research, development and in some cases demonstration will be necessary. Priority areas will include those that address the minimising of geological risk, the progressive reduction of the "man-interface" through increased automation and the environmental aspects associated with mining at increasing depth. Non-conventional extraction techniques also need to be developed to ensure the exploitation of future reserves.

Objectives:

- To improve run-of-mine coal quality without increasing product price by developing more selective mining methods and better material conveying systems.
- To undertake R&D into key areas which improve mine productivity while reducing production costs.
- To examine advanced extraction systems to enable coal to be won cost effectively from progressively deeper seams.
- To undertake RD&D activities in the next five years related to in-situ conversion technologies allowing exploitation of the energy from coal in remote and offshore seams.
- To ensure that health and safety is properly addressed and not detrimentally affected by any R&D project.

Total Estimated Cost of RD&D: £40-60 million

Summary

The economics and environmental acceptability of utilising UK coals depend on each step of the extraction-beneficiation-utilisation process. For example, the method of extraction significantly affects the emissions from coal combustion. In economic terms, the cost of coal is a function of productivity, flexibility and reliability etc in the extraction operation.

For this reason, it is important that R&D is undertaken into coal exploration and extraction in the areas of surface and underground

mining, together with RD&D into non-conventional underground extraction. Due attention needs to be given to R&D undertaken in other countries, where this is relevant to the UK situation.

3.1 Background

The UK coal mining and mining equipment supply industries have traditionally been at the forefront of mining technology, exporting equipment and expertise worldwide. However, the UK mining industry is now having to face the challenge of exploiting deeper coal measures, giving rise to problems that many of the other coal producing countries have not yet had to face.

In order for the UK to capitalise on these existing reserves, the coal extraction industry will therefore need to :

- improve current mining methods, particularly with respect to coal quality;
- develop the ability to extract coal from seams at greater depths;
- develop novel methods to exploit remote and off-shore coal; and
- maintain high standards of health and safety.

Successful R&D in these areas will, in addition, provide renewed export markets for extraction technology.

In this context, "extraction" is taken to mean the recovery of the energy content of the coal. This could be the recovery of coal without changing its chemical state (ie, conventional mining), or by in-situ conversion to produce a different chemical state which can then be recovered and utilised. Certainly it is inconceivable that far offshore reserves could be exploited using current conventional mining techniques.

Approximately 80% of current UK coal production is deep mined with the remaining 20% produced by opencast mining operations. The exploitation of deep coal may be conveniently considered under two headings, namely conventional mining and non-conventional extraction. Conventional deep mining covers the winning of coal from the coal seam using rotary/impact cutting machines, hydraulic powered supports and a variety of conveying systems, generally in longwall coal face configurations. The development of roadways and other infrastructure in support of these mining methods are also key areas of interest, since it is often these which limit the overall production capability. Other less widespread (in the UK) mining techniques, such as continuous miner production, etc, are also included, since, provided the enabling technologies are optimised (eg, roof bolting etc.), these systems can compete with longwall mining in terms of viability.

Existing mining systems are not conceived and executed from a "total system" concept but are a loose assembly of essentially disparate subsystems. Whilst the individual subsystem components may perform well in isolation, disunion and mismatching can occur in the complete system. This, coupled with restrictive manpower practices, has resulted in reduced machine utilisation with consequential reductions in investment returns.

Progress in conventional mining methods and associated infrastructure has been an evolutionary process, minimising risk and allowing a progression to technically advanced and operationally robust systems with considerable competitive advantage.

Since the principal use of coal in the UK is in steam raising for power generation, it is the energy content of the coal rather than the coal itself which is sought. In-situ conversion and remote recovery is therefore an option. These non-conventional recovery techniques require the energy content of the coal to be extracted as a fluid, either through chemical conversion or by creating a coal-liquid slurry.

Alternative non-conventional extraction techniques include:

- underground coal gasification;
- complete combustion underground;
- pyrolysis;
- quenched combustion to produce high temperature steam;
- solvent digestion using a coal derived oil;
- aqueous phase liquefaction using high temperature water;
- supercritical gas extraction pyrolysis;
- chemical comminution to produce a coal slurry;
- microbiological degradation to produce methane;
- hydraulic mining; and
- liberation of coal bed methane.

A study by the NCB in 1980 concluded that of these techniques, only underground coal gasification showed any real promise. Since then, however, considerable technological advances have been made, particularly in the areas of drilling, hydrofraccing and biotechnology, and other options need to be appraised.

Opencast, or surface mining, undertaken by contractors for British Coal's Opencast Executive, primarily utilises large earth moving machinery and blasting technologies.

3.2 Current Status of R&D

British Coal's current deep mining technical research is mostly short term and is aimed at improving the present technology of conventional mining, health and safety aspects and the associated infrastructure. Much of this work is performed in conjunction with the major equipment suppliers.

The Opencast Executive of British Coal undertakes limited R&D principally in the areas of environmental effects/amelioration technologies and restoration work. The Department of the Environment has also funded work in this area to support land use planning policies of the Government and local planning authorities. R&D into mining technology is mainly undertaken by the contractors or equipment suppliers, since the onus is on them to either cut production costs to maximise profits or to sell equipment. Current R&D (mainly through sponsoring university research) is focused on blasting vibrations, geotechnical engineering and the development of expert systems for geotechnical risk analysis and environmental impact.

3.3 Future Requirements for RD&D

Conventional Underground Mining

Due to depletion of the thicker more shallow reserves, the UK coal industry will need to mine both the more shallow thinner seams and the deeper thicker coal deposits in the medium term, sometimes in disturbed and weak ground. It will, in addition, need to at least maintain current cost levels if it is to compete effectively with imported coals. Improving coal quality, particularly with respect to ash, sulphur, moisture and fines contents, will also be a major driving force.

The UK mining industry has established standards for health and safety which are internationally recognised. The move to mining in thinner seams or at greater depth will pose additional problems for the underground workforce, and any programme of R&D must not in any way degrade these standards. It is therefore axiomatic that any R&D project will pay proper attention to these issues.

Areas of future R&D which will address these key needs are:

- Exploration

The purpose of exploration is to determine the geological structure so as to minimise risk, to optimise underground layout and to enable coal to be mined efficiently, cleanly and reliably. The ability to use deviated surface boreholes and to improve the resolution of surface seismics will assist in reserve location and definition. At the same time increasing the range of in-seam seismics beyond the 300-500m currently achievable and linking this technology to that of in-seam drilling will enhance the knowledge base in advance of the mining operation. Considerable success has been achieved in both surface and in-seam seismic techniques overseas (eg, Australia) and possibilities of benefiting from this experience need to be considered. The possible integration of in-seam and surface borehole data to provide a three dimensional model of the reserve to be worked, could in the future, provide an expert system to enable the effective minimising of geological risk.

In-seam drilling, which is problematic due to the soft nature of UK coals, also offers scope for improved methane drainage, or pre-drainage for extraction and utilisation, something that is already a growing requirement due to the global warming concerns discussed in Section 2.

Conventional mining methods are applicable to extracting coal to depths of around 1200 metres. However, substantial reserves of thick seams are known to exist at depths up to 2000 metres. An early task of the Coal R&D programme will be to quantify and characterise these reserves. This is also particularly relevant with respect to the non-conventional in-situ conversion techniques discussed later in the module.

- Access

Access to coal reserves can be divided into strategic development (i.e. developing new seams, areas and major service roadways), and replacement development drivage to develop new coal producing units. Strategic development (including shaft sinking) is mainly performed in "all stone" and "mainly stone" strata using drill-and-fire systems or tunnelling machines. Some scope exists for UK R&D into shaft sinking technology, particularly for deeper shafts (eg, 1,200-1,400 metres deep), however there is also a need for technology transfer from overseas. Increased opportunities for utilising small diameter shafts for ventilation, manriding and advanced coal transportation techniques may well require R&D to be undertaken in areas such as raise boring and headgear design. In addition, the possible use of large diameter shafts (i.e. >8m) requires attention, due to the advantages offered for large equipment transportation.

Consideration is currently being given to the use of shallow tunnels to access new reserves from existing mines. Such tunnels (say 50m below surface) would effectively be civil engineering structures, avoiding the need for costly deeper access developments or the use of further surface curtilages. A vital factor affecting the cost of a tunnel is the type of strata through which it is driven. Thus the shallow tunnel concept would allow selection of the best and most cost effective strata for tunnelling. Final access to the reserves would be achieved by either an underground shaft or drift. Since these techniques are already in use in the civil engineering industry, little R&D will be required in this area.

The need for high speed in replacement drivage is paramount for the successful operation of longwall systems, particularly retreat longwall, where development ratios in excess of 3.5 times the retreat face travel may be necessary to ensure the continuity of face production. Development performance is probably the most significant factor arresting the growth of retreat mining systems. In-seam drivage is, however, a shorter-term business priority for the coal producer and therefore falls outside the scope of this proposed strategy.

- Mining method

The coal to be extracted will occur in increasingly thin seams for shallow depth strata or at greater depths for thicker coal measures. Percentage recovery will also be of increasing importance. Present longwall technology is currently not considered feasible or economic in these circumstances. R&D in the medium time frame should therefore concentrate on refining longwall techniques or developing alternative extraction systems to enable these reserves to be exploited. Areas of R&D could include the integration of face operations, shortwall extraction, the use of continuous miners in "multiple entry" or "finger-panel" configurations, longwall systems for deep reserves and "submarine mining" (using mechanical coal winning systems with water providing the transport medium and, to a limited extent, the roof support medium). Stress relieving measures, strata control in weak ground using advanced powered supports, and improved materials and mineral handling will also be required.

Significant quantities of coal in thinner seams has a lower sulphur content and consequently, in the short term, there may be a requirement to extract this coal (probably not by using longwall methods) for blending purposes. It is conceivable that a non-profit making colliery (or seam or area) may need to be maintained in operation purely as a source of "sweetening" coal.

Once extraction is completed in an area, rapid face-to-face transfer of equipment is required. The main benefit in shortening the time required to salvage, move and install equipment, would be the increased utilisation of equipment and the consequential reduced capital requirement. In addition, the shorter time needed would make the working of smaller blocks of coal economic. Many of the methods used elsewhere may not be applicable to the UK because of the differences in conditions. However, research should investigate the overseas methods, techniques and equipment, to see if they can be used or modified to improve UK performance in this area.

- Automation

Automation is important in mining operations as it impinges on areas such as exploration, access drivage, mining operations, machine health, optimising machine utilisation, process status, etc. Although automation will necessarily increase as a matter of course, there is, however, a need for underlying R&D to ensure that the potential productive capacity of the whole mining "system" is maximised and realised. In order to automate any system, several requirements must be satisfied:

i) reliability of equipment

ii) appropriate sensors for measurement of the state of the process/sub-process

iii) data communications

iv) appropriate hardware and software for data processing

v) control of the process/sub-process.

To achieve these requirements in a cost effective manner will necessitate the transfer of significant enabling technologies from other industries eg data protocols, communications, software etc. Safety criteria specific to the mining industry will need to be applied including the requirement for "intrinsic safety" of electrical equipment.

Although the automation of machines and systems is very much in the equipment suppliers best interest, commonality of protocols and interfacing is vital to achieve full effectiveness. Consequently the underlying R&D would ensure that all the disciplines that comprise automation are coordinated.

- Infrastructure

The necessary gains in productivity in mining operations, and the consequential cost reductions, can only be achieved if the appropriate infrastructure is in place. The underground environment is a hostile one, and as operations go deeper and productivity requirements increase, so problems are exacerbated. The main areas of concern, particularly from the health and safety viewpoint, are the risk of fires (particularly conditions conducive to spontaneous combustion), explosions associated with methane concentrations, asphyxiation from "Blackdamp" (ie, reduced oxygen in mine air), airborne dust levels and noise. Although these problems are "traditional" in nature, the optimum solutions may not be. Areas of particular interest for R&D include methane drainage and utilisation, microbiological oxidation of methane, the use of small diameter boreholes for face ventilation, improved monitoring of the mining environment and the possible use of mine methane for refrigeration.

Access to the more remote, deeper or thinner seams, together with the expectations of the reduced number of personnel working underground, will necessitate developments in transportation technology. Advanced transportation systems need to be flexible and efficient, and in this respect three specific areas emerge for future R&D, namely faster personnel transporters, better and more automated materials handling, and higher capacity conveyors with no "extra space penalty". Efficient transport systems depend, to a large extent, upon roadway conditions, reinforcing the need for further progress in the area of access (eg, increased use of roofbolting techniques, etc).

Consideration will need to be given to the use of diesel engines underground, owing to the on-going speculation concerning the possible carcenogenic effects of diesel fumes.

Although "communications" has been addressed in the context of automation of the mining system (where it provides the vital interface between control and operation), the development of faster, more reliable sensing, signalling and verbal communication systems is becoming increasingly important to enable productivity improvement to be sustained. Specific R&D requirements may well include localised signal processing, artificial neural network allowing more autonomous operation, personal cordless communication and associated electromagnetic propagation arrangements for roadways and faces (eg, infrared or microwave frequencies).

- Coal quality

The supply of appropriate and consistent coal quality to the requirement of the customer will be a fundamental factor in maintaining or increasing market share. Quality requirement will be specified in terms of calorific value, ash, moisture, sulphur and chlorine content, with penalties for non-compliance. Reliable and accurate on-line coal monitors (discussed more fully in Section 5) are therefore required to verify quality, facilitate blending and to feedback corrective information into the production cycle. Coal preparation effectively begins at the coal face, where much can be done through good practice, better discipline at the coal face and advanced shearer guidance systems to minimise fines production and ash content.

Possibilities may also exist for limited underground coal preparation, enabling a considerable proportion of the mined mineral matter to remain underground and not be hoisted to surface only to be washed out during coal preparation and disposed of in surface spoil heaps.

Size grading should also be regarded as a quality requirement since significant problems have been experienced by users in both fuel handling and combustion due to high fines content.

Perhaps the single largest challenge to the UK coal industry is the requirement to lower sulphur content and hence assist coal users to comply with EC directives on SO_2 emissions. If this is not done, UK coal will find it increasingly difficult to compete with lower sulphur imported coals or other fossil fuels.

- Environmental impact of mining operations

The environmental impact of deep mining operations at the surface consists of gaseous emission (methane, carbon dioxide, etc), subsidence, waste disposal, water pollution and surface buildings. Possible areas for R&D include the disposal of colliery waste by "backfilling", further use for "minestone", utilising abandoned workings for municipal and toxic waste disposal and minimising water pollution resulting from either mine discharges or contamination of the groundwater table.

- Preservation of unwanted capacity

Mine workings are, with the exception of shafts and major roadways, relatively short-lived structures due to ground pressure. As demand requirements change, it may be desirable to "mothball" mining capacity for periods of time. R&D in this area could make reopening of mine workings, or their use for non-conventional extraction, an economically attractive proposition, thereby providing much greater flexibility in meeting energy demands.

Non-Conventional Extraction

Non-conventional extraction methods will have to be developed if the bulk of UK's indigenous reserves are to be exploited. Such methods should therefore be reappraised owing to the recent advances in the enabling technologies associated with them. Depending on the outcome, a feasibility study could then be undertaken, leading to more detailed R&D.

Prima facie, underground coal gasification (UCG) seems to be the most favourable option, being potentially both technically feasible and commercially viable. Other in-situ processes (eg, methane drainage, hydraulic mining, chemical comminution, degradation to methane, pyrolysis etc) remain less advanced for bulk coal applications.

Trials to date with UCG technology, together with recent advances in directional drilling, hydrofraccing, biotechnology and borehole lining, mean that this technique could be developed to compete with conventional mining techniques for exploiting the deeper, thinner higher rank coals typical of both on- and offshore reserves in the UK. A sensible proposal for a development programme for UCG, involving two European field trials, is currently being considered by the CEC under their THERMIE programme. The Department are proposing to contribute to the first field trial though the Coal R&D programme which will, if successful, lead on to a demonstration at pilot scale.

There is, however, a need for further studies and R&D (and possibly demonstration) into certain aspects of in-situ conversion, particularly product handling at surface, the possibility of applying the technique from existing off-shore oil production platforms and, most importantly, some of the institutional problems associated with this type of extraction (eg, environmental impact etc). As has already been discussed, an early study undertaken will examine UK coal reserves, including deeper coal measures, and this will highlight the extent to which non-conventional extraction technologies are required.

Surface Mining

Although most of the Opencast Executive's R&D expenditure is currently directed towards environmental and restoration issues, the selection of the mining method to be used on a site is pertinent to the planning consent procedure. Consequently whereas equipment choice is left to the contractor, scope exists for collaborative R&D into new extraction techniques such as additional production from the highwall using augering techniques. In addition, the degree of exploration required to delineate a block of coal for surface extraction is considerably greater than that for underground mining. R&D into areas such as verticality of boreholes could improve the accuracy of exploration and hence reduce geological risk.

Most UK opencast sites are small and short lived compared with overseas operations in the USA, Australia, the Republic of South Africa, Indonesia, Colombia, Venezuela etc. Little value can therefore be derived from developments undertaken overseas, which tend to be very capital intensive.

4. COAL PREPARATION

Aim: To assess, develop and promote cost effective coal preparation technology which improves the quality of coal sold to the various markets, thereby ameliorating the environmental impact arising when that coal is utilised.

Rationale: The preparation of run-of-mine coal to enhance its economic and environmental attraction, needs to be considered as a means of supplementing or augmenting downstream cleaning techniques. Technologies are emerging that offer promise. Thus a balanced approach is needed which combines enhanced coal preparation with more advanced utilisation and "clean-up" technologies. Since more beneficiated products may well be unsuitable for conventional fuel handling systems, advances will need to be made in these areas too.

Objectives:

- To appraise, over a five year period, the environmental benefit and the economics of using advanced coal preparation techniques to improve coal quality as a supplement to downstream pollution abatement.

- To develop technologies that could cost-effectively reduce the sulphur and chlorine contents of coal.

- To undertake a review of the markets and economics for lower ash, higher calorific value fuels.

- To develop technologies that could progressively reduce the free moisture content of fine coals to improve their handleability and calorific value.

Total Estimated Cost of RD&D: £7-10 million.

Summary

Considerable improvement in the environmental acceptability of utilising coal can be effected through careful preparation processes. A number of emerging technologies promise major reductions in sulphur and ash content in the coals sold on to the end user. However, a significant amount of R&D work is necessary to ensure early commercialisation.

R&D is required in all areas of coal preparation, namely physical (wet and dry), chemical and biological processing.

4.1 Background

Coal Preparation (or beneficiation) is an intermediary stage between the mining activity and the user involving coal breaking and sizing, coal washing or cleaning, and drying or dewatering. Run-of-mine (ROM) coal is a heterogeneous mixture of mineral and organic constituents and the purpose of coal preparation is to transform this into a saleable product, with properties that are consistent in all respects and which can be handled easily. This is achieved by utilising techniques that separate deleterious matter, ash and pyritic sulphur from the coal without altering the coal material itself, other than in terms of size.

Coal cleaning was initially used to prepare metallurgical coals for steel manufacturing. Its widespread application for steam coals is more recent and is due to various economic, environmental and technological factors.

With increased mechanisation of the mining operation, the selectivity of coal extraction has decreased. This means that the ROM coal can have a significantly higher and more varied shale content. Mechanisation has also led to increased proportions of small coal and fines in the ROM coal and increased dust levels at the face and at conveyor transfer points. This has in turn necessitated more widespread use of water for dust suppression.

Due to the increasingly stringent requirements for the control of sulphur dioxide emissions, there is likely to be an increasing demand for low sulphur coal. UK coals are comparatively high in sulphur content (1.6% average) relative to most internationally traded coal, which is mostly below 1% sulphur. In addition, many of the deeper longer-life mines also have coal with a high chlorine content, which increases the cost of maintenance in pf boilers. These environmental pressures have prompted considerable interest in advanced coal preparation techniques to determine the extent to which sulphur in particular can be removed from coal prior to combustion. This depends very much on how much sulphur is bound into the coal molecule (organic sulphur) as opposed to physically bound (inorganic, mainly pyritic, sulphur).

Existing coal preparation processes almost invariably use physical methods to clean the ROM coal. These predominantly rely on the difference in relative densities to separate coal from mineral impurities.

4.2 Current Status of R&D

British Coal's R&D concerns in the coal preparation area have concentrated on plant reliability and utilisation, product quality, environmental constraints of sulphur reduction and waste disposal, and cost reduction.

A considerable amount of R&D effort has consequently been invested in gaining a fundamental understanding of the froth flotation process, particularly to improve performance with low rank coals. Advanced dewatering technologies have also required development, including vacuum filtration and centrifuging.

4.3 Future Requirements for RD&D

Coal preparation's basic purpose is to provide the customer for that coal with a product of a desirable, known and consistent quality. As such, it is very specific to the end use market. However, a number of requirements are common to all the markets. Future RD&D will be directed toward the following key technologies, which need further development to ensure that this purpose is achieved, namely:

- the reduction of sulphur content (inorganic and organic);
- consideration of preparation to achieve lower ash, higher calorific value coals as a premium fuel;
- the economic reduction of chlorine in the coal to reduce boiler corrosion and other problems in combustion processes;
- to reduce the moisture content of fine coals and hence improve their net calorific value and the handlability of coals with high fines content.

These objectives can best be addressed by improvements to existing (mainly physical property-based) preparation processes, and novel coal preparation technologies. It should be noted that only a certain amount of beneficiation is possible before the reduced yield of saleable produce makes the process uneconomic; there also remains the problem of dispensing of increased quantities of waste products.

Novel methods of coal preparation have been aimed principally at the removal of sulphur and the processing of fine coal. These have included physical, chemical and biological methods which have in general necessitated treatment on a batch rather than a continuous basis and at laboratory or pilot scale throughputs.

There is a need for a detailed appraisal of these various options, which will enable RD&D priorities to be established. In addition, careful characterisation of UK coals, pyrites and other associated minerals will be required to determine whether a particular process route is applicable.

The problem of chlorine in coal is complex and much work has been undertaken in an attempt to understand the form of the chlorine ions and their distribution within the coal structure. The chlorine ions are bunched and held within pores in the structure of the coal. The pores containing the chlorine have a wide size distribution, which depends on the "rank" of the coal. Cleaning coals with respect to chlorine is therefore very dependent on very fine comminution and vigorous washing. This process can be made more efficient through the use of hot water.

As far as current UK coal preparation practice is concerned, chlorine removal technology is essentially limited to minimising the chloride content of washing water, particularly in the fine coal circuits.

Waste products from coal preparation (eg, waste waters from wet techniques) require careful consideration when appraising new technologies.

- Wet physical methods based on relative density

Dense medium methods are already in use in cyclones as well as in laminar flow vessels, with the coal immersed in a suspension that has a density between that of clean coal and other mineral matter (e.g. magnetite and water). These systems can produce a product of precise ash content and calorific value, depending on the inherent characteristics of the basic coal. R&D is required to extend this application to fine coal (<0.5mm) to try to improve both the removal of sulphur and coal recovery.

Spiral concentrators, hydrosizers, water-only cyclones and the "Multi-G" separator warrant consideration.

- Wet physical methods based on surface properties

The removal of fine pyritic sulphur by froth flotation can be improved by using two stage reverse flotation with the primary froth being refloated to produce a cleaner final product. Column flotation, particularly using "microbubbles" to effect the flotation, is of particular interest, with a number of trials on-going in the USA and elsewhere. The use of liquid carbon dioxide as a frothing agent, as opposed to water, air and surfactants, may hold considerable advantages. This may need some R&D work.

Agglomeration, caused by adding a light oil to a vigorously agitated slurry of fine coal, is a relatively easy and effective alternative to froth flotation for fine coals. Very fine coal can be separated in this manner with high recovery levels. Oil liberation, removal and recovery would need to be enhanced to make agglomeration economically attractive.

- Other wet physical methods

High gradient magnetic separation (HGMS) of impurities in fine coal, such as pyritic sulphur, is possible by using a magnetised matrix to attract weakly paramagnetic materials. Although magnetic separation is possible after "seeding", the availability and cost of suitable magnets have prevented the process being operated at a commercial scale. The resulting slurry of fine coal would also require dewatering using conventional equipment or thermal drying of the filter cake on a scale that is not yet proven; it may be more attractive to combust the slurry as a coal-water mixture (see following section).

- Dewatering/drying technology

A major problem of deep mined coal is high fines and moisture content, causing considerable handling difficulties in the final product.

In addition, intensive coal preparation itself requires large quantities of water, which can exacerbate the problem of final product moisture content. As a result, a number of advances have been made in dewatering and drying technologies, particularly in the fine coal process streams. Techniques have included pressure filtration, recessed plate filter presses, agglomeration, chemical treatment with "superabsorbents", mechanical dewatering, and directly heated rotary drying.

With increasing legislative demands on waste water quality, considerable attention will need to be given to water cleaning technology.

The benefits of coal-water mixtures (CWM) are discussed in more detail in Section 5. A totally integrated preparation and utilisation cycle for CWM would obviously avoid many of the problems associated with the dewatering/drying and subsequent handling and supply of coal to the point of use.

- Dry physical methods

Dry physical preparation of fine coal could feasibly be integrated with pf milling at the power station (or at the mine, with dense phase pneumatic or hydraulic transport to an adjacent power station). This is discussed further under the coal handling and supply section. Although dry cleaning suffers from the problems of dust and increased scale of operations, it would considerably reduce many of the problems associated with high mositure fines, tailings ponds, etc.

- Chemical methods

Chemical cleaning is under development in several countries, the aim being to produce very clean coals with sufficiently low sulphur and mineral matter content to enable their combustion without the need for any form of desulphurisation either during or post-combustion. Such clean coals would have certain niche markets and would only be viable at high revenues, due mainly to the smaller yields.

These methods generally involve the reaction of finely ground coal particles with hot selective chemical solutions which can be recovered for re-use. Possible technologies include oxidation, microwave irradiation, displacement, and hydro-desulphurisation.

- Biological methods

The microbiological desulphurisation of fine coal using a range of iron and sulphur oxidising micro-organisms is currently the subject of an EEC collaborative R&D project. However, the coal needs to be finely ground and a controlled residence time in the bioreactor is required to allow the treatment to access the sulphur. The product would then be in the form of wet fines which require either dewatering or utilisation as a coal-water mixture.

The possibility also exists of using bacterial methods to remove pyritic sulphur from lump coal using a heap leaching approach, as is the case for copper ore.

5. COAL HANDLING AND SUPPLY

Aim: To stimulate RD&D into handling and supply technology for coal (or other coal-based media) to the point of consumption, addressing operational or environmental deficiencies in existing or emerging coal utilisation/conversion processes.

Rationale: The emergence of advanced clean coal technologies for coal utilisation necessitates the development of enhanced coal handling and suppply technologies. These will allow the full potential of this utilisation technology to be realised. This will require several fundamental studies into the nature and dynamics of various coal flow media, leading to the development and demonstration of specific technologies holding promise.

Objectives:

- To undertake R&D leading to demonstration of reliable, useful and cost effective "on-line" analysis and measurement equipment which will assist in process control at all stages in the coal cycle.

- To investigate the cost effective preparation and use of coal-water-mixtures for supplying advanced utilisation technology or as an integrating medium between enhanced coal preparation and utilisation.

- To undertake fundamental studies looking at the dynamics of coal particle flow in pipes that supply coal to the point of combustion. This will enable the development of models and technology to enhance burner efficiency and reduce NO_x emissions.

- To undertake an early appraisal of options for coal handling and supply to the relevant market, including multi-phase flow of coal slurries, bunker design and milling technology, and to initiate R&D to address key problems and technological "gaps".

Total Estimated Cost of RD&D: £10-15 million.

Summary

The economics and final emission levels arising from coal utilisation depend in part upon the coal handling system between the mining/preparation processes and the point of use. In addition, novel methods of supply are being considered to enable coal to be used in a different form.

5.1 Background

After preparation, beneficiated coal requires handling, possibly stockpiling and blending, bunkering, loading and transporting. Most of the "supply side" handling technologies and problems are similar to those on the "market side", and these will be discussed together below.

72% of British Coal's marketable output is distributed by rail, 28% by road. Distribution by rail (virtually all of power station coal) has greatly improved in recent years, with increased use of "Merry-Go-Round" (MGR) trains, hauling up to 1,000 tonnes per train in 32 tonne capacity hopper wagons. There is a necessity for careful control and scheduling of trains to avoid delays, particularly at collieries without bunkerage facilities. Examples exist elsewhere in the world of highly advanced bunkerage and loading technologies. Distribution by road (mainly to non-power generation markets) is usually by covered tipper lorries because of their relatively low operating and maintenance costs.

Coal delivered for use in coal-fired power stations is discharged over grid screens into one or more track hoppers which in turn discharge the coal onto a conveyor belt. Magnets or "trash" screens remove any tramp metal or large debris prior to the coal passing onto elevating conveyor belts. Depending on requirements, the conveyors either discharge into station bunker(s) via a travelling conveyor, or on to surface stockpiles via a boom stacker. Mobile scrapers are used to form the stockpile into the conventional "whaleback" shape and compact the coal to prevent spontaneous combustion. Recovery from stock is either by bucket-wheel excavator feeding on to conveyors or scrapers feeding chutes back on to conveyors to the station bunker(s). Coal is then drawn from the station bunker via mill feeders, mixed with air and passed into the rod/roller or ball mills for comminution to pulverised fuel. A classifier is used, in circuit with each mill, to ensure the correct size distribution, with the oversize fraction passing back to the mill. The uniform pf is then blown directly to the burners with each mill supplying a number of burners. The splitting of the coal flow to the different burners is simply by a number of pipeline bifurcations or, particularly just prior to the burners, trifurcations.

While coal handling at power stations is generally an efficient and well developed activity, representing only a small part of the overall process, other industrial users often find it a significant proportion of their total cost. In this respect, pneumatic systems are finding increasing application in smaller scale operations.

Pneumatic systems for handling coal can be classified as either "dense phase" systems, which use compressed air to move "slugs" of coal, or "dilute phase", which use fans to transport more dilute coal-air mixtures. Dense phase systems have the advantage of not blocking so easily and because the conveying velocities are lower, reduced product degradation and pipe wear occurs.

With increasing interest in large industrial coal-fired CHP installations and smaller scale coalfield power stations, different handling and supply systems may be appropriate. Considerable development work will be needed in this area to address these requirements.

An alternative approach to coal supply is the use of coal-liquid mixtures (CLM), which have been considered as direct substitutes for heavy fuel oil for process heating, power generation and particularly industrial/commercial steam raising. The economics of using CLM is however highly dependent on oil prices.

Considerable work has been undertaken in the UK since the 1970's, mainly by equipment manufacturers, to determine the feasibility of using coal-oil mixtures (COM) and coal-water mixtures (CWM) as fuel. This work has concluded that COM is generally not an economic fuel option, since in the 50:50 ideal blend of coal and oil, only 30-40% of the energy is provided by the coal making its use highly dependent on the price of oil. On the other hand CWM is a more attractive proposition, with all the heat content being provided by the coal.

CWM consists of approximately 70% coal, 29% water and 1% of chemical additives to disperse and stabilise the suspension of coal in water, and to control its viscosity. CWM is prepared by grinding coal to give a broad spread of particle sizes, typically in the range of pf or finer. This broad range is required to give a high concentration of coal in water, resulting in a fuel with a calorific value about half that of fuel oil.

Recent developments in cleaning fine coal to produce low ash, low sulphur coal, have enhanced the interest in CWM, since part of the water used in the cleaning process can be used as the liquid phase for the CWM, avoiding the need for intensive dewatering. The integration of a CWM plant with a coal preparation plant is a possible future option. Total integration of CWM preparation and utilisation, ie, wet preparation, hydraulic transport and CWM firing into coal boilers would hold many advantages.

Substituting CWM for fuel oil does however mean that the capacity of the boiler will fall due mainly to the fouling of the heat exchange surfaces, but also to the reduced calorific value of the fuel and the need to evaporate the water. In addition, facilities using CWM would require the retrofitting of either electrostatic precipitators or baghouse filters to remove the fly ash produced. The cost of these modifications will obviously affect the economics of CWM.

5.2 Current Status of R&D

Little R&D has been conducted into coal handling between the coal preparation stage and delivery at the power station. R&D on raw coal at the power station has included stockpiling practices to avoid spontaneous combustion, coal flow and wear reduction in bunkers, and reducing spillage at coal transfer points through chute design and alignment.

The milling operation to produce pf has benefited from R&D into areas such as classifier performance, mill vibration, and the wearing of mill materials (particularly wearing surfaces on grinding elements).

R&D into pf transportation from the mills to the burners has included pipe erosion, the dynamics of particle flow in pipes, the behaviour of pf flows at bifurcations and trifurcations, avoidance of the "roping" of pf flow and subsequent uneven splitting between burners, the measurement of coal flow, and pf deposition in pipes and the associated risk of spontaneous combustion and coal dust explosions.

R&D into coal-derived fuels for industrial furnaces has been extensive both in the UK and overseas (notably the USA and Japan) and has included the examination of CWM combustion characteristics in test rigs, the effects of particle size and size distribution on CWM rheology, the production and use of CWM in the commercial market sector, stability (during transportation and storage) and the development of burners for the firing of CWM. Full scale trials have been undertaken in Canada, and CWM technology has been introduced into pilot scale gasification plants. Long distance pipeline transport of CWM has been applied in the USA for a number of years, eg, the Mojave project.

5.3 Future Requirements for RD&D

An increasing requirement exists in coal handling systems for instantaneous, accurate "on-line" analysis, particularly for ash and moisture content (and hence the calorific value), but also elemental analysis (eg, sulphur, nitrogen, sodium, potassium, etc). Such systems would find numerous applications in mine grade control, run-of-mine monitoring, sorting, blending, coal preparation plant control, stockpile management and monitoring at point of consumption. At present, a number of systems are commercially available based on X-ray backscatter, gamma-ray absorption, inherent radiation and neutron stimulation. The cost, accuracy and ability to detect full continuous flow in real time vary enormously, and RD&D is needed to ensure the optimum system is developed. Studies to correlate the fundamental chemical properties of coals with plant performance are also required. "Feed forward" capabilities (as opposed to "feedback") offer obvious additional advantages.

Although the use of CWM as a burner fuel has been extensively studied, the main purpose of this work has been to replace oil in retrofit situations. However, in the longer term, it may also be used to feed low sulphur/low ash coal into gasifiers and pressurised combustion systems, as the product of wet coal desulphurisation during coal preparation, or as part of a totally integrated CWM preparation/utilisation system.

Further assessment of the viability of CWM slurry fuel sprays is also needed, as in the long term, the economics for combustion of such fuels may prove attractive. The work would concentrate on reducing or eliminating the need for expensive additives, or reducing the cost of such additives.

There is a continuing need for both underlying studies of particle flow in pipes in order to optimise pf handling systems, and accurate flow measurement systems for pf in pipes. The degree of importance has increased with the need to control the air/fuel distribution to achieve optimum efficiency and minimum emissions of NO_x. Qualitative performance can be obtained using two-phase flow modelling methods, but more quantitative mathematical models are needed. The effects of bifurcations and trifurcations will also require further R&D.

Further R&D of raw coal handling techniques, specific to particular market sectors, may be required, including multi-phase flow, eg an appraisal of the use of raw coal slurries as a transport medium (particularly for pit head to nearby power plant, or from rail discharge to power plant) and further consideration of the advantages of dense phase pneumatic systems to power generation, and the behaviour of coal in bunkers (e.g. the "rat holing" effect, where coal sticks to the sides of the bunker/silo and only a central plug is drawn off, coal "bridging", lining wear etc). Emerging milling technologies, such as fluid energy milling, may also warrant appraisal. Weathering and other degrading effects due to open air surface stockpiling may necessitate the stock-piling of higher quality coals, produced by advanced coal preparation techniques, under cover.

6. COAL COMBUSTION PROCESSES

Aim:	To improve the economics and environmental acceptability of conventional coal combustion technologies.
Rationale:	Coal combustion represents the primary use of coal in the UK. It is used predominantly as pulverised fuel (pf) for power generation. It is likely that many existing pf based power stations can continue operating for at least another 15-20 years. Apart from coke manufacture for the steel industry, coal's prime industrial use is in combustion for steam raising, to provide typically process heat and/or power. Environmental and commercial constraints mean that it is unlikely that new coal-based plant will be built for some time. It is, therefore important to undertake R&D that will help to ensure that both pf and industrial coal combustion remains a competitive option. The focus will need to be on improved efficiency reduced environmental impact and lower first costs of retrofit technologies. RD&D aimed at the latter will overlap to a degree with that undertaken in coal preparation, as the use of coal-water mixtures and techniques to reduce sulphur content could prove to be of significant benefit.
Objectives:	• To undertake R&D that results in a better understanding and characterisation of conventional combustion processes. • To develop techniques that inhibit or control the formation of emissions (solid, liquid and gaseous) associated with combustion processes. • To undertake R&D into systems for improved post-combustion clean-up of gaseous and particulate emissions. • To undertake RD&D that results in improved operating efficiency through the use of higher temperature and pressure steam conditions.

Total Estimated Cost of RD&D: **£15-25 million.**

Summary

Coal combustion, in particular for power generation, represents the single largest method of coal utilisation in the UK, accounting for over 90% of 1989 consumption. The combustion process will remain the predominant means of coal utilisation for the foreseeable future. Competition from natural gas in the power generation market, combined with economic and environmental pressures, will severely restrict the construction of new coal-based plant based on existing types of combustion plant. Instead new coal-based plant will most likely be based on the use of advanced integrated power generation systems. These systems are designed to address many of the environmental problems associated with coal use, while simultaneously improving the overall process thermal efficiency. These systems are discussed separately in Section 7.

However, these environmental pressures result in a need for continuing R&D into the combustion process, in order to ensure that conventional combustion processes can continue to be economically viable and environmentally acceptable. The research will need to encompass existing pulverised fuel (pf) combustion processes used in power generation, together with systems that are typical of industrial use. The environmental constraints associated with the use of existing combustion systems mean that the timescales associated with R&D in this area are near-term (3-5 years) rather than the longer term associated with technologies that might be used in advanced power generation systems.

6.1 Background

Although coal characterisation is of fundamental importance in understanding the impact of coal use, a significant amount of both near- and medium-term R&D is targeted at coal combustion. Analysis of coal consumption data by market sector shows why this is the case.

Table 6.1 below gives a breakdown by sector of UK coal consumption for 1989.

Table 6.1
1989 UK Inland Coal Consumption

Sector	Consumption, x10^3 tonnes
Fuel Industries	
Power Stations	80,560
Coke Ovens	10,792
Other	1,865
Final Users	
Domestic	5,712
Other Industry	7,497
Public Administration	875
Other Consumers	187
Total	**107,488**

(Source: UK Energy Statistics 1990 - Governmental Statistical Service/ Department of Energy)

As Table 6.1 shows, 10% of consumption was used for coke production associated with metallurgical industries (iron, steel and others) and the remaining 90% used for various combustion processes. Around 2% of coal use was associated with the cement industry. It is further evident that over 80% of the coal used in combustion was dedicated to steam raising by the Electricity Supply Industry (ESI) for power generation purposes. What is certain is that the ESI will continue to be the dominant user of coal in the near- to medium-term. It is, therefore, important to understand the constraints that are, or will be placed on coal combustion in this market sector when defining the RD&D that is required.

Perhaps the most significant constraint comes as a result of the UK's agreement to reduce SO_2 and NO_x emissions in accord with the limits set out in the European Community's Large Combustion Plant Directive - 88/609/EEC. Table 6.2 shows the target reductions in emissions with which the UK has to comply.

In addition, limits have been set for any new coal-fired plant with a thermal input >50 MW.

A second factor, although not necessarily a constraint, is that the ESI has been privatised. This will result in pressure to increase plant operating efficiency, which is also important to market sectors outside the ESI.

Table 6.2
Emission Control Targets
(% Reduction from 1980 Levels)

Year	SO_2	NO_x
1993	20	15
1998	40	30
2003	60	Not yet agreed

The industrial market for coal, whilst not directly affected as yet by EEC legislation, will have to comply with emission limits yet to be set by the HM Inspectorate of Pollution (HMIP). At present HMIP have prepared consultation papers defining limits for emissions associated with coal-fired industrial boiler plant. Guidance Notes will be issued, once the consultation process has been completed. These will help to define what RD&D will be needed to ensure that, in the longer term, coal could be an economic alternative to other fuels.

6.2 Current Status of R&D

Coal combustion research is currently being undertaken in those areas that can be broadly classified as follows.

- Characterisation of combustion in pf furnaces;
- studies of other combustion systems for industrial use, eg, fluidised beds;
- coal characterisation with respect to slagging, fouling and corrosion of combustion and other equipment;
- understanding and control of combustion conditions that lead to the formation and subsequent emission of atmospheric pollutants, including systems such as in-furnace sorbent addition;
- mathematical modelling of combustion behaviour;
- use of coal/waste fuels in industrial furnaces;
- improving stability and control of industrial combustion systems;
- assessment and development of post-combustion systems such as electrostatic precipitators, selective catalytic and non-catalytic reduction (SCR & SNCR) of NO_x and improved FGD technologies.

Much of the research, being undertaken in the areas outlined above, relates to existing combustion systems. It is only through a more complete understanding of the combustion process and the influence of coal characteristics, both physical and chemical, that the necessary improvements can be made to ensure that the combustion of coal will remain both economic and environmentally acceptable.

6.3 Future Requirements for RD&D

Considerable progress is already being made in understanding the combustion process and those factors that influence efficiency and associated emissions. As it is likely that existing types of combustion system (especially in power generation) will be the predominant means of coal utilisation in the UK for the next 15-20 years, it is important that the R&D focuses on improving efficiency and that any modifications/retrofit technology also endeavour to reduce the first costs associated with the combustion plant. Future RD&D requirements will fall broadly into those categories defined in Section 6.2 above. Particular areas of importance are summarised below.

Characterisation of Combustion in pf Furnaces

Validated data are required on gas composition, velocity and temperature distributions in pf furnaces. Such data are needed for validating simulation packages currently available and for the ongoing development of combustion models. Various laser techniques, currently being investigated and refined, may offer the possibility of obtaining the necessary data. Different approaches for obtaining the data also need investigating.

By combining the work undertaken in characterising the combustion process, together with that undertaken to get a better understanding of the associated NO_x chemistry it should be possible to develop improved low NO_x burner and associated technology. This will be an important area for R&D in the near term.

Other Industrial Combustion Systems

A likely medium- to long-term development is the increased use of fluidised bed combustion systems in the industrial sector. In addition, greater emphasis may be placed on processes to include the use of waste and sewage (discussed later). However, fluidised beds are not without operational problems. More research is needed to understand how coal's physical and chemical properties affect the combustion process, thereby leading to the development of improved systems and/or process control techniques. As already discussed, further work is required to fully understand and mitigate nitrous oxide (N_2O) emissions, where associated with the use of new and developing technologies. The use of UK coals with their high chlorine content may also result in a need to mitigate the associated HCl emissions.

Coal combustion in industry is not restricted to the raising of steam in boilers/furnaces, some of which may be used to raise power via steam turbo-alternators. Coal is also used in cement manufacture where the use of alternative calcining techniques requires further investigation. At present R&D is also being undertaken, mainly in the USA, that focuses on the use of coal as a fuel in diesel engines and directly-fired gas turbines (using slagging combustors). The latter technologies are likely to be more relevant in the near- to medium-term for industrial use, including small-scale power generation. In the longer term they might find use in advanced power generation systems for utility scale operation. It will be necessary to assess their relevance and to identify any areas for R&D to be undertaken in the UK.

Coal Characterisation/Science

The areas in which further coal characterisation/science studies can have an impact are discussed in some detail in Section 9. Work to date has concentrated primarily on relating properties of coal ash to global parameters associated with the coal (acidity, elemental composition etc). Unfortunately, the mineral matter in coal is not homogeneous, and it is necessary to understand better the influence of this inhomogeneity on ash formation and deposition in furnaces. This will then lead on to the development and demonstration of techniques that enhance the economic and environmental performance of the boiler systems. One result of research in this area may be the identification and use of additives that enhance the combustion process, resulting in less slagging, fouling or carbon in ash.

Sensitivity to trace elements such as lead, arsenic, cadmium and mercury is also increasing. It will, therefore, be important to get an understanding of how they are distributed between the organic and inorganic constituents of pf, and the implications thereof.

Understanding of Pollutant Formation and Control

Work needed in this area is primarily associated with gaining a better understanding of NO_x and N_2O formation. The NO_x formation process is known to depend on temperature and local concentrations of hydrocarbon and nitrogen radicals, formed during de-volatilisation. Clarification of the kinetics is needed in order to be able to produce simple but reliable models that can be utilised in simulation and control packages. There is even less understanding of N_2O chemistry associated with fluidised beds, and this will need further investigation.

The other major pollutant whose emissions are currently limited by environmental legislation is SO_2. Most systems currently used or proposed are post-combustion. However, various types of in-furnace sorbent injection systems have been, or are being developed. Such systems may be particularly relevant for industrial boilers/furnaces. A study investigating the availability and limitations of such systems is needed, one result of which would be the identification of areas needing RD&D.

Another approach that can help to minimise and control the emissions associated with utility scale plant is the use of natural gas. This can be co-fired in the furnace, with appropriate R&D identifying how to maximise the benefits, or it can be used to improve the overall plant efficiency by firing in a gas turbine. The exhaust gases from the latter (essentially vitiated air) are then used to support combustion in the furnace. Again R&D is needed to assess its technical, environmental and economic impact.

Post Combustion Clean-Up Systems

Post-combustion systems are aimed primarily at reducing emissions of NO_x, SO_2 and particulate matter. The need for these, and the rate at which they will be applied, is largely determined by the need to comply with environmental legislation. Section 2.1 to 2.3 discusses the current UK position on the application of these technologies with particular reference to SO_2, NO_x and the use of electrostatic precipitators. It is likely that environmental constraints will become tighter. Therefore, it will be important to assess initially, the operating limits of available technologies, with a view to identifying associated RD&D needs. In undertaking such an appraisal, it will be necessary to take into account (in particular for combustion plant found in the ESI) the residual life of the plant, the rate at which technology needs to, and can develop, against the installation and use of some of the advanced clean coal power generation technologies.

Modelling of Combustion Behaviour

Considerable progress has been made in the development of large computer codes for simulation of pf furnaces. However, there is still a need for good experimental data generated from the other areas outlined for further research, that will allow validation and improvement of the codes.

Use of Coal/Waste Fuels

There is growing interest in the use of refuse and sewage sludge, in combination with coal, as a fuel for power utility and industrial furnaces. In part, this is due to the "non-fossil fuel obligation" associated with the ESI's privatisation, and in part due to legislation associated with the regulation and diminishing number of land-fill sites. Work is needed to understand the combustion behaviour of coal/waste mixtures, characterise mineral matter content and to develop plant operating routines that comply with environmental constraints. This work would be complementary to the Department's already ongoing biofuels programme.

Control Monitoring of Combustion Performance

In order to maintain the benefits associated with efficient combustion (with respect to fuel utilisation and pollutant emissions), it will be necessary to provide accurate control of fuel and air to individual burners; this need will be dependent on the type of firing system. Research is required into control methods based on measurement techniques that continuously monitor the coal flame's physical and chemical characteristics within the furnace. Techniques are currently being researched that will ultimately need to be durable, reliable and easy to use by non-expert personnel. This work can be further extended to include R&D into the use of expert systems, allied to control techniques.

7. ADVANCED POWER GENERATION

Aim: To secure a long term market for coal by undertaking RD&D into advanced power generation alternatives.

Rationale: Several factors including increasing environmental concerns, the relative price and availability of fossil fuels and developments in gas turbine technology, will likely mean that any new coal based power technology will be based on one or more of a number of emerging "clean coal" technologies. It is, therefore, important to undertake R&D that could lead to the successful demonstration of the most appropriate technology(ies) for the UK, so that it(they) are ready for commercial exploitation when the need arises.

Objectives:

- To set up one or more Working Group(s) to advise and assess the RD&D requirements of advanced clean coal technologies that can be used for large scale power generation.

- To undertake a programme of R&D, identified as necessary by the Working Group(s), that will lead to the successful demonstration of appropriate technology(ies) at a scale sufficient to enable commercial uptake.

- To demonstrate the application of advanced power generation technology(ies) to the point where it (they) are commercially viable in the UK.

Total Estimated Cost of RD&D: £250-600 million.

Summary

The application of technologies to reduce emissions associated with coal combustion has primarily been associated with the reduction of particulate matter, SO_2 and NO_x. Limits on emissions have been set by the EEC as outlined in Section 7. All newly constructed plants will have to meet these new limits.

However, the privatisation of the ESI has resulted in an upsurge of interest and intent to build power stations based on the use of combined cycle gas turbine technology (CCGT). National Power, PowerGen and several of the Area Boards intend to build power stations based on this technology. Several factors have influenced these decisions, of which the two most important can be summarised as follows:

- the high generating efficiencies of CCGT plant, low capital cost and speed of construction ensure a faster return on invested capital. However, the price and availability of natural gas will also influence CCGT plant uptake;

- the use of natural gas in CCGT technology makes a significant contribution to reducing emissions from the UK thereby enabling compliance with the EEC Directive. Natural gas contains little or no sulphur and its use in CCGT plant results in reduced CO_2 emissions per kWh generated.

It is recognised that in the longer term, with gas prices likely to increase, advanced coal-based technologies will become competitive. At the same time these technologies will have to comply with increasingly tight standards on emissions of SO_2, NO_x and possibly CO_2. Several technologies have been, or are being developed, that address the use of coal in an efficient and environmentally benign manner. These are generally referred to as "clean coal" technologies, primarily with reference to SO_2, N_2O and NO_x emissions, but also holding the prospect of increased generating efficiency and, therefore, lower CO_2 emissions per unit of electrical output.

Ultimately, environmental constraints will be a very significant factor in determining which of the clean coal technologies is most suited for power generation. At the same time it is important to recognise that many of these technologies still have scope for further development aimed in particular at improving the overall thermal efficiency and reducing the capital costs.

Thus any R&D that requires undertaking needs to be directed in a manner that ensures that the status of the technologies is such that sufficient data are available for direct comparison of operating efficiencies, environmental, capital and operating costs.

While the economic and environmental acceptability of any new technology will become increasingly important, it is recognised that power generation companies will only invest in what are considered to be proven technologies. It is likely therefore, that larger scale demonstration of one or more of the technologies will be required, taking into account overseas experiences.

7.1 Background

Increasing concern for the environment has led to the recognition that any new coal-based generating plant will be determined by the environmental legislation that it has to satisfy. Limits on emissions and associated waste streams are likely to be set on the basis of what the best available technology can achieve. As a result of ongoing R&D in the developed world, several technologies have been or are being developed that improve generating efficiencies from the present level associated with pf plant of around 37.5% (GCV) to over 39%. These technologies seek simultaneously to address environmental issues such as SO_2,NO_x and particulates.

A summary and brief description of the various technologies that can be used for power generation is given below:

- Atmospheric Fluidised Bed Combustion (AFBC)

Air is used to fluidise a bed of solid particles, typically limestone and coal. Combustion usually takes place at around 850-950°C, which inhibits NO_x formation and prevents slag formation. Two modes of operating are typical: bubbling or circulating. In the former, steam is recovered from in-bed tubes, in the latter the combustion chamber is waterwalled. Heat is also recovered from the flue gases, with a steam turbine used to generate the electricity.

- Pressurised Fluidised Bed Combustion (PFBC) - Combined Cycle Operation

This system works on the same principle as a bubbling fluidised bed, but at pressures of typically 15 bar. Electricity generation is achieved by means of a steam turbine, using steam generated from in-bed tubes, and a gas turbine, which makes use of the high pressure hot exhaust gases.

- Integrated Gasification Combined Cycle (IGCC)

A gas (typically hydrogen and carbon monoxide) is produced by the gasification of coal together with air or oxygen and steam. Several processes have been developed, each of which has different features. In combined cycle operation, the gas is combusted in a gas turbine to produce power, with additional power being generated by a steam turbine. The steam is produced by heat recovery from the gas turbine exhaust, the gasifier and depending on the process, the gasifier product gas cooler.

A further development, that appears to hold prospect for improved generating efficiency at lower capital cost, is the integration of a gasifier with a Humid Air Turbine (IGHAT). This system makes use of low temperature waste heat to humidify the combustion air that is fed to the gas turbine, thereby enhancing the power output and improving the overall generating efficiency.

- Topping Cycle

This is effectively a combination of gasification and fluidised bed combustion technology. Typically the gasifier is air blown at pressure and the coal is partially gasified. The remaining char is fed to a fluidised bed combustor (AFBC or PFBC). The gasifier "fuel gas" is fed to a gas turbine generator, to produce power. In one possible configuration the gas turbine exhaust is used to provide the oxidant for the fluidised bed combustor. Steam recovered from the combustor is then used to drive a steam turbo-generator to produce further power. Other configurations are possible which may result in higher overall efficiencies.

- Magneto Hydrodynamics (MHD)

MHD concerns the passage of a hot gas (typically >2000°C) seeded with cations through a venturi channel that sits in a magnetic field. The gas can result from the direct combustion of coal or gas derived from a coal gasifier (indirect). The seeded gas in effect acts as a moving element in a generator, inducing an electrical current which is passed through an inverter to produce a.c. power. Heat is then recovered from the exhaust gases and by means of a simple steam cycle produces more electricity.

- Fuel Cells

Fuel cells are electrochemical devices that convert the chemical energy of a reaction, directly to electrical energy. In a typical cell gaseous fuels (eg, hydrogen) are fed to the anode compartment and an oxidant, typically oxygen from air, is fed continuously to the cathode. The electrochemical reaction takes place at the electrodes producing a current. This process continues for as long as fuel and oxidant are fed to the electrodes.

Various electrolytes can be used, but fuel cells based on molten carbonate and solid oxide technology currently show the most promise for utility scale power generation. The potential exists for integrating fuel cells with coal gasification plant; the product gas (predominantly hydrogen and carbon monoxide) being used as the fuel delivered to the anode. The higher temperatures associated with these two types of fuel cell also offers the possibility of producing further power through heat recovery in a simple cycle steam system.

RD&D requirements for fuel cell technology are being addressed in a separate Department of Energy programme.

7.2 Current Status of R&D

Table 7.1 provides a simple overview of the status of the various technologies that might be used in advanced power generation systems. The majority of existing R&D in the UK addresses the use of conventional pf plant (see Section 7), IGCC based on the use of the British Gas/Lurgi slagging gasifier and British Coal Corporation's Topping Cycle. In addition to the R&D undertaken in the UK, several other IGCC processes have been or are being developed/demonstrated outside the UK. These include processes developed by Shell, Texaco, Krupps-Koppers, Dow and others. For comparative purposes, conventional and advanced pf plant fitted with FGD have been included in the table.

It is evident that all the technologies except the Topping Cycle, MHD and fuel cells are currently available in the market place. However, it is unlikely that any will find commercial application in the UK, at least until such time as the generating cost/kWh is competitive with:

a) power from existing pf plant retrofitted with low NO_x and FGD technology,

and b) the new generation of gas burning combined cycle power stations.

Alternatively, environmental legislation, coupled with a directive (as previously existed in the EEC) limiting the use of gas for power generation, could hasten the speed at which clean coal power generation technologies will become commercially viable.

7.3 Future Requirements for RD&D

By summarising in Table 7.1 the perceived advantages and disadvantages of the various technologies, it is possible to define areas in which RD&D is still required. The timescale represents an attempt to reflect the period over which RD&D will be required, in order to maximise the commercial and environmental benefits of each of the technologies. Two values for the overall generating efficiencies are given. The first represents what might be achieved if the technology were applied today, the second represents what ultimately might be achieved with further RD&D.

The RD&D requirements are not intended to be either a prescriptive or exhaustive list, rather to serve as an illustration of where further work is required. Indeed, the Department of Energy will set up one or more Working Groups to continually monitor and review RD&D requirements in this area. This will effectively maximise the scope for collaboration, resulting in the demonstration of the technology(ies) most suited to the UK. (It should be recognised that the results of research undertaken in other areas of the Coal R&D programme, such as coal handling/preparation, could have a significant impact on the choice of system(s) for demonstration.) In monitoring and reviewing the RD&D requirements for these technologies it will also be necessary to review and recommend the basic coal science R&D that will be needed to support and ultimately used to refine the technologies.

TABLE 7.1 SUMMARY OF STATUS OF VARIOUS TECHNOLOGIES FOR USE IN ADVANCED POWER GENERATION SYSTEMS

Technology	Advantages	Disadvantages
Conventional pf fired + FGD	Widespread experience with proven technology, although UK's first FGD plant not yet operational.	Waste disposal problem if Gypsum quality doesn't meet specifications, or plasterboard market becomes saturated and/or environmental constraints are tightened.
Advanced pf combustion + FGD	Improved steam cycle efficiencies. Use can be made of conventional FGD technologies.	Materials operate close to design limits. Can be difficult to control, and at present few plants (6) operational. Experience shows that difficulties are not insurmountable.
Circulating Fluidised Bed Combustion (CFBC)	Low temperature (800-950°C) operation inhibits NOx formation. Use of in-bed sorbent for sulphur capture (>90% capture possible). Good fuel burn-out due to long residence time. Therefore suitable for waste and other low grade/high ash fuels. Many systems in operation worldwide (>100) up to 150 MWe.	Costs associated with disposal of solid wastes. Most existing plant is for industrial use rather than power generation. Emissions not fully characterised.
Pressurised Fluidised Bed Combustion (PFBC)	Low NOx emissions due to low combustion temperature. Pressurisation enhances sulphur retention by sorbent (>92% capture). Relatively compact size. High efficiency at relatively low gas turbine inlet temperature vs IGCC. Suitable for re-powering.	Not many (3) systems in operation. Needs efficient gas clean up to minimise erosion and corrosion of turbine blades. Disposal of solid wastes. Emissions not fully characterised.
Integrated Gasification Combined Cycle (IGCC)	Several designs available commercially. Potentially lower quantities of solid product compared with other processes. High cycle efficiency. >99% sulphur capture. Can be retro-fitted to gas fired combined cycle plants. Ash converted into an inert slag.	Not yet commercially proven for power generation; although all system components are commercially proven.
British Coal Topping Cycle based on PFBG/PFBC or PFBG/CFBC	Ability to use wide range of fuels. Does not require air separation plant to provide O_2. Use of in-bed sorbent for sulphur capture.	Process yet to be demonstrated at pilot sale. Significant further development required. Needs efficient gas clean-up to minimise erosion/corrosion to gas turbine. Sulphur capture lower than IGCC.
Fuel Cells	High Electrical Efficiency. More environmentally benign than other technologies. Efficiency dependent of load and plant size.	Technology still in early stages of development. Only demonstrated at 5-100 KWe scale. Studies needed on how best to integrate with coal based plant.
Magnetohydro-dynamics (MHD)	Potentially low emissions and high efficiencies.	Commercial plant only at conceptual stage. Much work still needed on channel design, materials of construction, seed recovery and reprocessing, air heater technology.

Generating Efficiency % (GCV)		No Years to Market Availability	Considered to be Commercially viable	Areas for future R&D	Timescale over which R&D is necessary
Now	Probable				
37.5	39	Now	Yes, but to-date UK only committed to one type of FGD.	As outlined in Section 7.	Near
42	44	Now	Yes, but all operating experience is overseas.	Use of different materials for the supercritical heat exchange regions.	Near to medium
37.5	39	Now	Yes; but plant size to-date typically less than 100 MWe equivalent.	Co-combustion of coal with wastes. Treatment and disposal of solid wastes. Measurement and control of N_2O emissions.	Near to medium
41	43	Now	Currently in process of being proven. Can improve efficiency through use of reheat and supercritical conditions (see Advanced pf combustion)	Similar to CFBC but also: Hot gas clean-up. Improved metallurgy for supercritical operation, and gas turbine components. Assessment and disposal of solid wastes.	Near to long
42	46	Now	Currently in process of being proven, with demonstration plants now under construction.	Advanced materials for GT and heat exchangers. Quantifying effect of variable coal quality. Advanced fuel supply systems (see Section 5). Optimising integration of GT and steam cycles (10-15% improvement possible). Optimising retrofit options.	Near to medium
(43)	47	5-10	Still a design concept with many technical issues to be resolved.	Hot gas clean-up. Optimisation of process route. Understanding of erosion/ corrosion associated with alkali metal vapours. GT blade life modelling. Characterisation of waste streams.	Near to long
35	55	10-20	No, still in early development stages for utility scale generation.	Power densities/integrity of stacks; stack manufacturing techniques; process integration.	Near to long
-	50+	20+	No, many of the components still need further development.	Channel design/materials of construction. Seed capture and recycling. Flyash collection. Air heater technology. Electrode life.	Long

* - Gas turbines are assumed to operate at the same efficiency in each of the tecnologies where they are needed.

8. OTHER COAL CONVERSION AND UTILISATION PROCESSES

Aim:	To assess and support RD&D of existing and emerging coal conversion technologies that may result in their being capable of commercial uptake, or more effective operation.
Rationale:	In the longer term, as the availability of gas and oil become limited and their associated costs increase an opportunity will exist to supply coal derived fuels for industrial, commercial, domestic and transport needs; coal being the world's most abundant fossil fuel resource. Technologies will need to exist that can exploit the opportunities so provided, and these technologies will need to be underpinned by RD&D that will ensure compliance with environmental standards at commercially viable cost.
Objectives:	• To undertake economic, environmental and technical assessments of existing and proposed conversion technologies. • To support R&D in areas that are identified, in the above assessments, as requiring further work, so that the technologies can be successfully demonstrated.

Total Estimated Cost of RD&D: £50-100 million.

Summary

As the availability of oil and gas becomes limited and their respective costs increase, alternative ways of producing substitute fuels will need to be commercialised. Coal represents the UK's largest fossil fuel resource, with a lifetime estimated to be in excess of 300 years at current rates of consumption. Indeed, known coal reserves worldwide are at present more than double those of oil and gas combined. As the availability of oil and/or gas becomes limited and their market price increases, then so the production of liquid and gaseous fuels from coal should become economically viable. Ultimately oil and gas prices would become limited by the costs of producing substitutes from coal. This assumes a continuing dependence on the use of hydrocarbons as transport fuels and as feedstocks for the chemical and other industries.

Coal gasification and liquefaction processes are currently being developed in the UK. The economics currently associated with these process routes mean that their use will likely be in the medium to long term, unless oil and gas prices were to remain at historically high levels for an extended period of time. Nevertheless, strategic

considerations make it important that the processes are available when required, without compromising safety and environmental considerations.

Carbonisation processes have been used for many years to convert coal into coke and other products, but continued development is necessary to extend the range of coals that can be used, to improve the product and to make the process more environmentally acceptable. Techniques are also being developed to replace the use of coke in metallurgical processes by the direct use of coal. Such techniques will acquire increasing importance as existing process equipment reaches the end of its useful life.

8.1 Background

Coal conversion concerns the application of technologies that produce gaseous, liquid or modified solid fuels from coal. At present, only the use of coal for coke production in the metallurgical industries is commercially viable. The other process routes will become increasingly important as oil and gas become supply limited. At the same time the direct use of coal in metallurgical processes will reduce the demand for coke but may necessitate improved coke quality. Work is currently being undertaken in each of the three areas, which are now discussed separately.

Gasification

Coal gasification typically results in the production of a gas mixture which is combustible due to the presence of hydrogen and carbon monoxide. Three approaches have been and continue to be researched in the UK:

- gasification of coal with air producing a low calorific value (CV) gas comprising hydrogen, carbon monoxide, carbon dioxide and nitrogen. This gas is often referred to as "fuel" gas;
- gasification of coal in an oxygen rich atmosphere producing a medium to high CV gas (syngas) suitable for conversion to Substitute Natural Gas (SNG);
- gasification of coal in hydrogen, also known as hydrogenation, to produce SNG. The SNG is predominantly methane, but the UK process may be operated in a way that it co-produces significant quantities of aromatic hydrocarbons, such as benzene or non-fuel products;

In the above processes, most of the sulphur and nitrogen contained in the coal are converted respectively to hydrogen sulphide and ammonia.

These, together with any particulate carry-over, can be easily removed by commercially available catalytic and liquid absorption processes. This relative ease of removal of pollutants makes gasification an attractive route for the clean use of coal, provided economic viability can be achieved.

Another route to the production of SNG is the hydrogenation of coal; although not typically considered when referring to coal gasification. Nevertheless, it is an alternative route that is currently being investigated, by British Gas. Sulphur and nitrogen from coal feedstock emerge from the gasification/hydrogenation process as elemental sulphur and an aqueous solution of ammonia; both saleable products.

Currently the main interest is in the use of gasification processes is for advanced clean-coal power generation plant. This is separately addressed in Section 7. Therefore, in considering what further R&D is required, this section is restricted to application of technologies for the production of SNG as an intermediate product for use in secondary processes, primarily, in domestic and industrial markets.

Liquefaction

The production of liquid fuels from coal is primarily aimed at the provision of transport fuels. Liquefaction processes can be broadly divided into two classes: direct and indirect. Direct processes partially break down the coal structure, enabling it to be dissolved in a recycled solvent. The resulting coal solution is then hydrocracked to yield products in the desired boiling ranges. Indirect processes, in contrast, break down the coal structure totally by gasification. Liquid products are then generated by synthesis. Indirect processes are inherently less thermally efficient than direct processes due to the thermodynamics of the two reaction sequences. Their overall process economics are considerably less attractive than those calculated for direct liquefaction.

No direct liquefaction process has been demonstrated on a large scale anywhere in the world. British Coal has, however, been developing a direct liquefaction process for many years, leading to the construction of a pilot plant facility at Point of Ayr in North Wales.

Other coal liquefaction processes have been primarily investigated in the USA, Germany and South Africa. Only the latter exploits the technology commercially due to a combination of large reserves of low cost coal and difficulties with access to oil. Indeed, its first oil from coal was produced in 1955. The technology is based on indirect liquefaction, where the coal is first gasified to produce syngas which is then fed to a Fischer Tropsch synthesis. But for the special circumstances in South Africa, it is unlikely that at present the process would be commercially viable. Another alternative could be the use of microbial techniques, which might be expected to require less sever process conditions. This route, therefore, could potentially be more economic.

Carbonisation and Other Metallurgical Uses

Carbonisation of coal primarily concerns the production of coke. The process involves the heating of coal in the absence of air. This leads to the release of volatile matter, which in the past was the main objective. The carbon residue, coke, is now the product of main interest. Its manufacture currently accounts for the equivalent of around 10% of UK coal production, the majority of which is used in the steel industry. While the market has declined in line with the contraction of the steel industry, it is still important. A major concern for the continued exploitation of this market is the declining availability of prime coking coal. A further concern is the need for improved environmental controls in the process.

Some coke has been replaced by the direct injection of coal into blast furnace tuyeres and this is expected to increase. However this will demand higher quality specifications for the remaining coke. Work has also been undertaken on steelmaking processes that are based entirely on coal, but the economics of these have yet to be fully established.

8.2 Current Status of R&D

Gasification

The British Coal Topping Cycle apart, most of the R&D that has been or is being undertaken in the UK can be attributed to British Gas. The latter's work has been associated with two processes. The first involved the use of a slagging gasifier, jointly developed with Lurgi, to produce syngas for further conversion to SNG. A demonstration plant has been operational at Westfield in Scotland, since 1977. Initially, at 300 t/d coal throughput, with a 500 t/d plant commissioned in 1985. The Department of Energy has recently collaborated in trials using various UK coals of different rank.

The second process is that of coal hydrogenation, the process being developed at their Midlands Research Station in Solihull. A small pilot scale plant (5 tonne/day) has been successful in demonstrating the process. In British Gas's process the coal is hydrogenated using hydrogen produced from the residual char by the carbon steam reaction. The pilot scale research programme has been completed recently.

Liquefaction

As discussed in 8.1, British Coal have constructed a pilot plant facility at Point of Ayr. The facility is due to be commissioned during 1991 after which there will be a programme of plant and performance trials that are currently being defined. The project is being supported by funding from the Department of Energy and the EEC amongst others. These trials will serve to highlight areas for future R&D, in particular what further development might be required to bring the process to technical and commercial viability at large scale.

At present, the only R&D associated with coal liquefaction in the UK addresses the direct, or solvent extraction processes.

Carbonisation

The subject of carbonisation is closely linked to basic coal sciences. Given the importance of coke to the iron and steelmaking industries, much R&D has been and continues to be undertaken into developing correlations between basic coal properties and the quality of coke. (Indeed some of these correlations have been used to try to characterise coal combustion, with only limited success.) The declining availability of prime coking coals, as mentioned previously, has resulted in recent research aimed at showing that various blends can be used in the coking process without loss of product quality. Research is also currently ongoing that addresses the substitution of coke by direct coal reduction techniques. Much of the current research is aided by funding from the European Coal and Steel Community (ECSC).

8.3 Future Requirements for RD&D

Gasification

Apart from the application and use of gasification processes in advanced power generation systems as already discussed in Section 7 there is limited scope for further RD&D for the production of SNG. While the production of SNG for the domestic/industrial market is unlikely to be a near to medium term requirement, several factors indicate a need for some degree of continuing research into the production of SNG. These factors can be summarised as follows:

- the unresolved political issues in the Soviet Union and Middle East; two areas from which natural gas might be imported;
- expansion of the European Gas Grid limiting the quantities of gas available to the UK from other nations with North Sea gas reserves;
- current UK consumption/production figures encompassing all proven and possible reserves (as defined in the "Brown Book" for gas reserves) indicate guaranteed supply of around 30 years.

In particular there currently exists an opportunity to review the success of British Gas's programmes which could result in identifying future RD&D requirements. This could encompass work associated with basic coal science studies for different types of coal and their impact on the different end use processes.

Another possible area for RD&D is the development of small scale and environmentally benign gasification processes for application to industrial scale boiler plant.

Liquefaction

Based on the research already carried out by British Coal, it is possible to define further areas in which further research and development could advance the commercial scale introduction of coal liquefaction. These are as follows:

- fundamental studies on the relationships between coal properties, coal structure and liquefaction behaviour;
- assessment of potential R&D in alternative liquefaction techniques, both direct and indirect eg, hydropyrolysis, hydrogenation, etc;
- development of catalysts with improved activity, yield patterns and lifetimes;
- process development and optimisation, including improved hydrogen utilisation;
- investigating the options for integrating coal liquefaction, both direct and indirect processes, with conventional oil refinery operations leading to a "pioneer plant" appraisal and possible demonstration.

Carbonisation and Other Metallurgical Uses

Carbonisation research is now concerned almost exclusively with the production of metallurgical coke and the extraction and treatment of by-products from this process in ways that are economical and environmentally acceptable. The ECSC plays a major role in promoting such research. The areas where future work will be required are as follows:

- improving coke quality to meet the stringent demands of high productivity blast furnaces operating at high levels of tuyere injection and hence low coke rates;
- extending the range of coals that can be used in the coking process because of the limited availability of prime coking coals;
- reducing the levels of undesirable emissions from the process so that it can meet future legislative standards and public acceptance.

Direct injection of coal into blast furnace tuyeres has already made significant reductions in the amount of coke required for steelmaking and work is ongoing to increase injection levels. Other investigations are aimed at developing coal-based steel production routes which do not require coke at all. These will have to be pursued further to establish their economic viability at various scales of operation. Their adoption is likely to be gradual because of the high capital cost and long life of equipment dedicated to more traditional routes.

9. COAL SCIENCE

Aim: To develop a better understanding of the fundamentals of coal's behaviour in all processes for which coal is likely to be used as a feedstock or fuel.

Rationale: Unless there exists a basic understanding of how different coal characteristics can have an effect on each of the various end use technologies, it is very difficult to know how to optimise the technology with respect to environmental and economic considerations. It is only through a combination of basic coal science research and experimental work at different scales that this can be achieved. This section, therefore, addresses itself to the basic coal science R&D that is needed in support of the utilisation technologies described in Sections 6 through 8.

Objectives:

- To undertake fundamental research in support of new and emerging clean coal technologies.
- To undertake fundamental studies on the relationship between coal structure, mineralogy, composition and its behaviour in the various coal utilisation processes.
- To use the results obtained from the fundamental studies to develop meaningful correlations between coal type and performance in the technologies of interest.
- To assess whether or not these correlations lend themselves to the development of "on-line" analytical techniques, and if so, undertake the necessary development work that will allow the technique to be successfully applied. (See also Section 5.3 & 6.3).

Total Estimated Cost of RD&D: £5-10 million.

Summary

All coal utilisation processes are affected by the quality of coal fed to the process. Coal quality, in turn, is not just a function of consistency but is also dependent on the physical and chemical components of the coal and the characteristics of these components. Unfortunately the impact of coal quality on different processes, process development and the environment is not sufficiently well understood to allow a detailed economic assessment for the use of a particular coal. Work is needed to develop and validate relationships between coal quality and economic performance in each

of those areas where coal will be utilised. For some coal utilisation processes, it may be necessary to develop "on-line" instrumentation/techniques which allow practical use of the information that is generated.

9.1 Background

Understanding how different coal characteristics affect its utilisation, by whatever means, is of fundamental importance. Ideally correlations should exist that enable different coals to be ordered according to the costs associated with their use in different processes such as combustion, gasification, pyrolysis and liquefaction.

The importance of each of the different characteristics of coal such as ash composition, maceral type, levels and types of impurities, hardness, volatiles content etc, will vary according to the different end use technology. For instance, ash composition and associated physical properties may be more significant to combustion and gasification processes than it is to liquefaction and carbonisation processes. Conversely the maceral composition of coal may be more significant to carbonisation and liquefaction than say to combustion and gasification. Volatiles concentration may be important to all, but for different reasons: to combustion because it determines combustion rate and resultant composition of flue gases, to carbonisation because of its relationship with the physical properties of coke that is produced. It is evident, therefore, that basic coal science research has an important and fundamental role to play in characterising how different coals will perform in each of the various end use technologies.

As coal combustion will likely continue to be the dominant use of coal in the UK in the near to medium term future, the combustion process is used below, **by way of example**, to show how different coal characteristics are important to the process. Similar analyses can be undertaken for each area of coal utilisation. This has been addressed, as appropriate, in each of the technology modules by indicating where further basic coal studies are required, as well as in 9.2 and 9.3.

Prior to combustion, the coal is pulverised in rod/roller or ball mills. Hard or abrasive coals can require more energy to achieve the necessary degree of size reduction, thereby reducing overall plant efficiency. Alternatively various mill components need more frequent replacement resulting in lower plant availability. The combustion process then comprises four steps over a few seconds: ignition, devolatilisation, combustion of volatiles and char (carbon) burnout. The efficiency and availability of the furnace are affected by the completeness, or otherwise, of the combustion process and the temperatures attained during the combustion process.

The main problems associated with the coal combustion process can be broadly summarised as:

- the formation of various nitrogen oxides (NO_x and N_2O);
- the formation of slag, resulting in reduced efficiency and poor heat transfer for conversion of water to steam;
- fouling of the higher level superheater and reheat tubes causing excessive pressure drop, and derating of boiler due to reduced heat transfer;
- corrosion and abrasion caused by coal ash particles impinging on boiler surfaces;
- the burning profile of the coal, which is largely dependent on volatile matter and the maceral composition.

Following the combustion process the flue gases are typically passed through electrostatic precipitation (ESP) for particulate removal (fly ash). It is known that the performance of ESP's is directly affected by the properties of the ash particles.

From the above it can be seen that coal quality is of significant importance to the coal combustion process.

9.2 Current Status of R&D

Characterisation methods are being developed and used to monitor combustion processes, to assess coals, to aid process development and to help assess the environmental impact of coal. Those areas of research currently being pursued can be broadly classified as follows.

- analysis of coal structure and mineralogy;
- measurement of physical properties;
- classification of behaviour of coal during combustion, gasification, liquefaction etc.

Coal carbonisation apart, no laboratory tests have yet been developed which correlate the performance of different types of coal in the various end use technologies that have been, or are being, developed. Further work is required before this goal is achieved.

9.3 Future Requirements for R&D

There is a general lack of validated data relating fundamental coal characteristics, in particular to performance of coals in gasification/hydrogenation and liquefaction processes. It is also possible that a better understanding of fundamental coal characteristics could lead to optimisation of the mining and coal preparation steps, as discussed in previous sections. Some data exist for combustion and pyrolysis, however, these have tended to regard the coal as being homogeneous which is not the case.

In particular, more work is required on understanding how properties such as maceral composition, nature and types of volatiles, nitrogen composition and char reactivity relate to the various coal utilisation processes, thereby leading to further process optimisation. At the same time it is recognised that coal sources and uses will change in the future. It is, therefore, of increasing importance that not only standard tests are developed which are relevant to processes currently used, but also tests that are relevant to processes that will be used in the future. In particular, operation at elevated pressure is common to most of the advanced clean coal technologies. It is through the development of standard tests that methodologies can be devised that will enable coals to be characterised with respect to their behaviour and/or performance in particular situations, eg, research on devolatilisation and pyrolysis at pressure.

Underlying the need to develop standard tests is a need for developing and improving analytical methods that allow a better understanding of coal structure and the coal to be fully characterised. These analytical methods may then require further development, possibly through the use of models, to allow on-line coal quality analysis. This would help to ensure that the coal utilisation can be continuously optimised.

A consequence of assimilating data from standard tests and use of better analytical techniques, is the possibility of assigning "fingerprints" or a minimum number of critical parameters to different coals. This would become of increasing importance when endeavouring to assess the likely performance or potential importance of coals imported into the UK.

APPENDIX 2

THE CRITERIA FOR ASSESSING PROPOSALS UNDER THE COAL R&D PROGRAMME

THE CRITERIA FOR ASSESSING PROPOSALS UNDER THE COAL R&D PROGRAMME

Project proposals will be judged against the set of criteria listed below, together with the type of questions that need to be answered by the proposal. Proposals will not necessarily rank highly against all the criteria.

Relevance - will the project help to satisfy one or more objectives of the Coal R&D programme?

Necessity - Can the end result be achieved as effectively by alternative methods?

Novelty - Is the information, technology, capability or end product under consideration already available, or likely to become available when required, either in the UK or abroad?

Credibility - Are the objectives of the project likely to be achieved in the time proposed in a cost-effective manner?

Exploitability - What will happen to the results of the research and development project if supported? What is the contractor's credibility in the R&D field and has he sufficient capital, and manpower, to complete the project? In the case of an end product or procedure, does he intend to be the ultimate manufacturer or user, or has he entered into an agreement with another firm for them to manufacture under licence or to purchase the results?

Dependence on Support - Why is Government support needed for the Proposal? Would the work go ahead at all, less effectively or slower without Departmental support? Would the Department of Energy have access to the information arising without Departmental support? Would there be national benefits from providing support?

UK Competitiveness - If the objective of the work is commercial, will the results benefit the UK, taking into account the effect on home and overseas competitors?

Need for Further Work - Is the proposed programme complete in itself, or is it likely to lead to further R&D programmes involving requests for additional support from the Department of Energy?

APPENDIX 3

THE DEPARTMENT OF ENERGY'S COAL TASK FORCE

- MEMBERSHIP AND TERMS OF REFERENCE

MEMBERSHIP OF THE COAL TASK FORCE

Chairman

Dr Eoin Lees, AEA Environment and Energy
Head of the Energy Technology Support Unit (ETSU)

Members

Dr David Halstead, National Power plc
Technology and Environmental Centre

Mr Jim Harrison, British Coal Corporation
Director of the Coal Research Establishment, Stoke Orchard

Dr John Lacey, British Gas
Programme Director, Substitute Natural Gas

Dr Chris Lawn, PowerGen plc
Manager, Research Programme

Dr Tom Lowes, Blue Circle Industries plc
BCC Energy Manager

Mr Trevor Massey, British Coal Corporation
Head of Technical Department

Mr John Monson, British Steel
Department Head, Teesside Laboratories

Mr Rex North, NEI International Combustion Ltd
Engineering Director

Mr Alan Oakes
Consultant and Former General Manager, BP Coal Australia

Mr Jim Perrin, Babcock Energy Ltd
Technical Director

Eur Ing Bill Ryder
Consultant and Former Executive of Babcock International plc

Professor Nick Syred, University of Wales College of Cardiff
Division of Mechanical Engineering and Energy Studies,
School of Engineering

Dr Alex Toohey, Shell Coal International Ltd
President of Trading and Development

Professor Alan Williams, Leeds University
Livesey Professor and Head of Fuel and Energy Department

TERMS OF REFERENCE OF THE COAL TASK FORCE

1. To advise the Department of Energy and its agent the Energy Technology Support Unit (ETSU) in developing and formulating, against programme aims and objectives set by the Department of Energy, programme plans for the Department's Coal R&D programme, taking due note of international programmes and any other relevant work.
2. In the light of the agreed programme, to advise the Department of Energy and its agent ETSU, on the technical and commercial merits of Coal R&D proposals and to make recommendations on the funding of individual projects which are submitted to the Committee.
3. To monitor progress of the Coal R&D programme against the agreed plans and evaluate its effectiveness in achieving the agreed objectives.
4. To provide a forum for continuing developments of the strategic, technical and commercial aspects of the Department of Energy's Coal R&D programme.